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THE METAMORPHISM OF THE SHUSWAP TERRANE OF BRITISH COLUMBIA

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ABSTRACT

The Shuswap terrane, exhibiting flow cleavage parallel to the sedimentary stratification over a wide area, has been regarded as a classic example of load or static metamorphism. An examination of the structure of the gneisses reveals a common quaquaversal habit due to the updoming of granite stocks into the flat-lying, deeply buried sediments. The effect of the upward thrust of the magma against a great load differs from the effect of load alone. In the latter case the pressure would be hydrostatic and the deformation resulting would be merely dilatational, and consequently without orientation of the constituent minerals. In the former case, however, the shouldering effect of the magma results in the compression of the strata normal to the bedding, and a complementary elongation of the strata in their long dimension, supplying the lateral relief necessary to cause an orientation of the minerals. This explanation applies both to the gneisses (Shuswap) and to the overlying schists (Beltian). The yielding of the intruded rocks by rock flowage, the result of an active thrust of the subjacent magma, clearly cannot be regarded as static.

INTRODUCTION

The Shuswap terrane affords a well-known example of a regional parallelism of flow cleavage to bedding in fairly flat-lying rocks. This condition has been attributed by some authors to load metamorphism, an interpretation which has not been accepted universally. In an effort to discover the cause of this particular type of metamorphism, this investigation was undertaken.

The Shuswap terrane, as defined by Daly,[1] is composed largely of

[1] R. A. Daly, "A Geological Reconnaissance between Golden and Kamloops, British Columbia, etc.," *Geol. Soc. Can. Mem. 68* (1915), p. 10.

gneisses of the Grenville type and a closely related intrusive granite, occupying an area 400 miles long and averaging 75 miles wide in the southern interior of British Columbia. The gneisses comprise a complex series of granitized sedimentary strata intimately penetrated and separated by orthogneiss sills. Foliated granites grade imperceptibly on one hand into massive granites and on the other into banded gneisses. Occurring within the gneisses are remnants of relatively unaltered sedimentary rocks, varying in size from small fragments to areas of several square miles. The whole assemblage is cut by innumerable pegmatite and aplite dikes. The gneisses are, to all appearances, basal, dipping under all other formations at the margin of the terrane.

At the eastern contact, the sill sediment complex is overlaid without angular discordance by the Beltian system, the rocks of which outcrop on the east side of the Shuswap terrane almost continuously from the "Big Bend" of the Columbia River south into Idaho and Montana. A thickness of 10,000–30,000 feet of argillites and quartzites with some limestone underlies the Olenellus zone of the Cambrian, usually with perfect conformity.

On the west margin of the Shuswap terrane are several areas of sedimentary rocks which, because of their isolation, cannot be positively correlated. In the key map (Fig. 1) they are shown as Beltian, following Bailey Willis.[2]

The cause of the metamorphism of the Shuswap gneisses and of the Beltian rocks long has been a source of contention. The characteristic feature of the metamorphism of these rocks, whether orthogneiss, paragneiss, schist, or slate, is that their cleavage is almost invariably parallel to the bedding or banding. In most places the rocks are gently dipping; dips of over 50° are rare, dips of less than 30° are usual, and dips of less than 15° prevail over large expanses of country. It is very apparent that the foliation and schistosity were acquired when the rocks were essentially flat-lying, as in general they still are.

The relations of flow cleavage to bedding and to folding, as set forth by Leith[3] in 1905, have been proved repeatedly since that date.

[2] "Index to Stratigraphy of North America," *U.S. Geol. Surv. Prof. Paper 71* (1912).

[3] C. K. Leith, "Rock Cleavage," *U.S. Geol. Surv. Bull. 239* (1905).

Flow cleavage is oriented in the direction of easiest relief of stress, or in the direction of maximum elongation of the deformed rocks, which in the case of folded rocks cannot be in the direction of the bedding

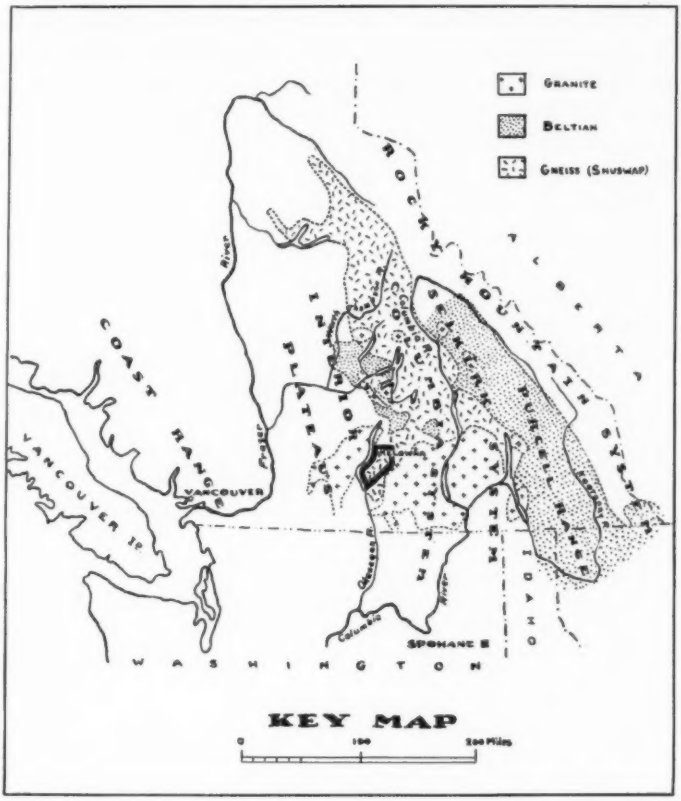

FIG. 1

except in isoclinal folds. In the Shuswap terrane isoclinal folding is absent, but over this great area flow cleavage parallel to the bedding is the rule. A cause other than folding must be sought to explain this type of metamorphism.

G. M. Dawson,[4] who first studied the Shuswap area, attributed the cleavage to the weight of the overlying rocks. Daly[5] followed this interpretation and enlarged upon it. He says: "Static metamorphism has two necessary features. It is directly due to burial and the stress involved is radial." Because of the rigorous parallelism of cleavage to bedding both in gneiss and sediments, and because of the lack of disturbance and lack of ordinary folding, Daly ruled out the possibility that the metamorphism was dynamic.

Daly made two assumptions to explain the intensity of metamorphism: (1) that the thermal gradient was higher at the time of alteration, since rocks of other ages buried at similar depths were not metamorphosed to the same extent; and (2) that volatile solvents were present in abundance (both trapped water in original sediments and magmatic water), to account for the salic quality of the granite, the abundance of pegmatite, the common transformation of intrusives into orthogneiss, and the prevalence of *lit-par-lit* injection.

This theory is inacceptable to a great many geologists because, at such depths as postulated, presumably the pressure due to the weight of overlying rocks would be essentially hydrostatic. The containing pressures of the rocks about any point would be equal to the weight of the overlying rocks, and there could be no deformation other than cubic compression.

Leith,[6] commenting on the metamorphism of the Shuswap terrane and that of the Grenville of the Adirondacks, doubts that such a structure is caused by load alone, because other terranes, once as deeply or more deeply buried, do not possess this structure. He adds that, in his observation,

> load has not produced static cleavage on any large scale. It is certain that rock cleavage is commonly a result of movement. It is associated with folds, joints, faults, and other structures uniformly indicating movement. The distortion of original structures and the presence of recrystallization, granulation, and rotation in cleavage all clearly indicate movement, which means the shortening of certain strain axes and lengthening of others. Load could clearly accomplish movement where there is opportunity for extension normal to compression, that

[4] "Geological Record of the Rocky Mountain Region in Canada," *Bull. Geol. Soc. Amer.*, Vol. XII (1901), p. 64.

[5] "A Geological Reconnaissance between Golden and Kamloops, British Columbia, etc.," *op. cit.*, pp. 40–49.

[6] *Structural Geology* (New York: Holt & Co., 1923), p. 130.

is, where there is opportunity for escape. . . . . In general it might seem that the opportunity for the lateral extension of the sediments under gravitational load deep below the surface is absent.

Before the controversy on load metamorphism arose, Van Hise,[7] in discussing the various manners of intrusion of igneous rocks, regarded as of prime importance the habit of magma rising *en masse* without breaking across the structures to a great extent. The invaded rocks, as they are raised and pushed aside by the magma, develop a slaty or schistose structure peripheral to the batholith. If the invaded rocks were hitherto undisturbed sedimentary rocks, the schistosity, developing in a direction normal to the pressure, is parallel to the bedding.

The writer had the opportunity, during the course of two summers, to become familiar with the gneisses of Okanagan Lake, but, feeling that these rocks did not tell the complete story, also spent several weeks about Shuswap Lake, and in the Selkirk section of the Beltian among the rocks on which Daly's theory was based. Van Hise's observations suggested an explanation of the metamorphism of the Shuswap and Beltian rocks. This article is an effort to show that his ideas are applicable here and that they furnish a more complete and satisfactory explanation of the problem than any other theory proposed.

The problem is necessarily divided into two parts: (1) that of the Shuswap gneisses the metamorphism of which is the result of the process of "granitization,"[8] and (2) that of the Beltian rocks, which have been metamorphosed without the addition of appreciable material from igneous sources. But arguments will be presented to show that the Shuswap is merely a highly altered phase of the Beltian. This point having been established, the problem becomes more unified.

RELATIONS OF SHUSWAP AND BELTIAN

The Shuswap series was named by Dawson,[9] and defined to include the great series of gneisses and enclosed remnants of sedimentary

[7] C. R. Van Hise, "A Treatise on Metamorphism," *U.S. Geol. Surv. Mono. 47* (1904), p. 708.

[8] J. J. Sederholm, "On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland," Part I, *Bull. Comm. Geol. Finland, No. 58* (1923).

[9] "On a Portion of the West Koolanie District, British Columbia," *Geol. Surv. Can. Ann. Rept., 1888–89*, p. 29B.

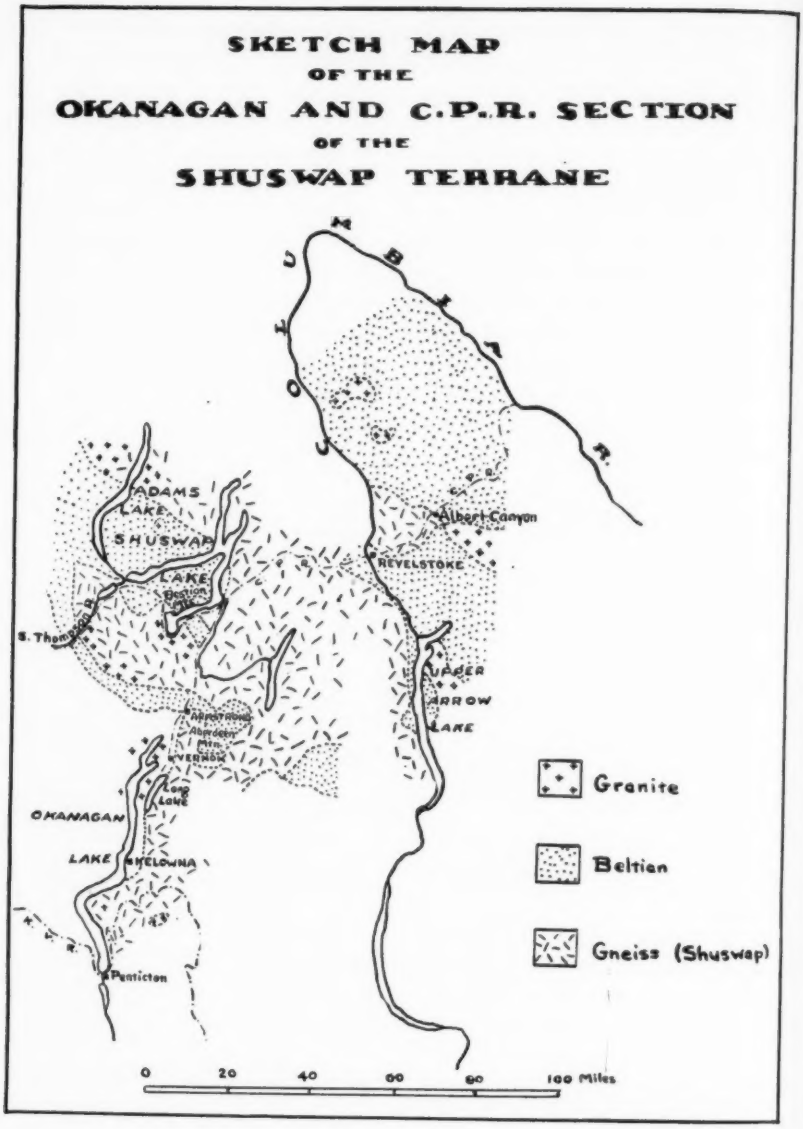
SKETCH MAP
OF THE
OKANAGAN AND C.P.R. SECTION
OF THE
SHUSWAP TERRANE
COLUMBIA R.
ADAMS LAKE
SHUSWAP LAKE
Albert Canyon
REVELSTOKE
S. Thompson R.
UPPER ARROW LAKE
ARMSTRONG
Aberdeen Mtn.
VERNON
Long Lake
OKANAGAN LAKE
KELOWNA
Penticton
Granite
Beltian
Gneiss (Shuswap)
0 20 40 60 80 100 Miles

FIG. 2

rocks which he believed to be the "fundamental complex" underlying any rocks which can be assigned to the Cambrian. Daly accepted Dawson's definition but also included in the Shuswap series (1) a thick group of non-fossiliferous sedimentary rocks occurring about the southern part of Shuswap Lake which had been called by Dawson the Nisconlith series and referred to the Cambrian; and (2) a great thickness of greenstones of volcanic origin, the Adams Lake series, which overlies the "Nisconlith" between Adams and Shuswap lakes. The writer, for reasons that will be apparent later, prefers to include all Dawson's Nisconlith in the Beltian.

Dawson and Daly regarded the Shuswap as Archean largely on the strength of its stratigraphical position and of its similarity to the "fundamental complex" of the pre-Cambrian Shield. Dawson did not discover a structural unconformity above the gneisses. Indeed, he noted[10] "a distinct tendency to parallelism of the strata or foliation with the adjacent borders of the Cambrian system" (Nisconlith).

Daly's principal evidence as to the Archean age of the Shuswap is an unconformity at Albert Canyon. Evidence is accumulating which does not bear out the idea of an unconformity between Shuswap and Beltian. This has been collected and summarized by S. J. Schofield,[11] some of whose arguments are presented on following pages.

It has been observed by Walker, Bancroft, Gunning,[12] and others, that the late pre-Cambrian rocks in various portions of the region grade into granitic gneisses both across and along the strike. Evidence seems to show that the granite responsible for the granitization of the sediments in the production of the gneisses is Mesozoic in age.[13]

Gunning[14] made a careful study of the critical zone described as

[10] "Geological Record of the Rocky Mountain Region in Canada," *op. cit*, p. 64.

[11] Unpublished manuscript.

[12] J. F. Walker, M. F. Bancroft, and H. C. Gunning, "Lardeau Map-Area, British Columbia," *Geol. Surv. Can. Mem. 161* (1929), p. 15.

[13] Bancroft, "Lardeau Map-Area, British Columbia," *Geol. Surv. Can. Summ. Rept. (1921)*, p. 110A; Gunning, "Geology and Mineral Deposits of Big Bend Map-Area, British Columbia," *ibid.* (1928), p. 151A.

[14] *Ibid.*, p. 150A.

an unconformity by Daly[15] and found that "fresh granitic dykes, including aplites and pegmatites that cut the gneisses, also cut the overlying sediments." Quoting further:

> No unconformity was noted. The gneisses are exactly similar to those encountered elsewhere in the granite-gneiss-sediment complex. The intimate manner in which the gneisses are interbedded with the sediments indicates that they have been formed by replacement and injection in the sediments by a granitic magma.

The writer also studied this contact and agrees with Gunning. The interlocking relationship between gneiss and meta-sedimentary rocks seems conclusive evidence that the gneisses were derived from those sediments.

Bancroft[16] has traced the "basement complex" from Ainsworth to the Selkirk section, and shows that the gneisses are not Archean but Beltian or Lower Paleozoic. Schofield[17] also pointed out the fact that between Albert Creek and the base of Daly's Laurie formation in which crinoid stems were found[18] (suggesting an infold of Paleozoic rocks), the thickness of strata is only 4,100 feet instead of the expected thickness, if the unconformity exists, of 25,000 feet of Beltian and 12,000 feet of Cambrian. He therefore concludes:

> It can readily be seen that the present status of the Shuswap series as Archean is very much in doubt and the general tendency is to place the greater part of the Shuswap series in the Beltian, with some in the Paleozoic in certain localities.

Little doubt remains that the Shuswap gneisses are granitized sediments, some of which are of Beltian age, though there is no reason why the granitization should necessarily be confined to the Beltian. The name "Shuswap" can be abandoned as the name of a series, since its significance as regards age has been lost; but there seems to be no objection to it as the name of a rock type.

[15] "A Geological Reconnaissance between Golden and Kamloops, British Columbia," *op. cit.*, p. 62.

[16] "Lardeau Map-Area, British Columbia," *op. cit.*, p. 109A.

[17] Unpublished manuscript.

[18] Gunning, "Geology and Mineral Deposits of Big Bend Map-Area, British Columbia," *op. cit.*, p. 142A; L. D. Burling, "Further Light on the Earlier Stratigraphy of the Canadian Cordillera," *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), p. 145.

THE GNEISSES OF THE KELOWNA AREA

The gneisses of the Kelowna area constitute the southwestern tip of the Shuswap terrane. This area lies along the central portion of Okanagan Lake, extending north almost to adjoin the southern margin of Dawson's Shuswap sheet, and southeast to the limits of the topographic map on the Little White Mountain divide.

Gneisses of Shuswap type are very extensive in this area and can be traced continuously from Penticton north to join the gneisses of the Shuswap area. Their western limit follows the valley of Long Lake and Okanagan Lake south of Kelowna. This line, at least north of Kelowna, is thought to represent a zone of faulting of considerable displacement, since the rocks to the west of it range in age from Carboniferous to Tertiary. The invariably rather flat attitude of the gneisses indicates a truncation and a relative upward movement of the gneisses along this line to allow the juxtaposition of the younger rocks.

To arrive at some conclusion regarding the age of the sedimentary rocks which form the foundation of the gneisses of the Kelowna area, it is necessary to go farther afield. The continuous mass of gneisses between Kelowna and the Columbia Mountains west of Revelstoke contains areas of relatively unaltered sediments in close association. Such an area occurs on Aberdeen Mountain, northeast of Vernon, where the rocks consist of carbonaceous shales with minor amounts of limestone. The carbonaceous character of the series renders it fairly distinctive, and it was mapped by Dawson as Nisconlith, which has later been referred to the Beltian.

The contact between these Nisconlith sediments and the gneisses is somewhat similar to that at Albert Canyon. The sedimentary rocks overlie the gneisses in perfect conformity; but the contact is an arbitrary one, since sedimentary beds are seen in the gneisses, and gneissic sills or granitized beds occur well up in the mass of relatively unaltered sedimentary rocks. A definite interlocking occurs between the two types. The conclusion is that it is the Nisconlith sediments, the structure of which is inherited in a large part of the gneisses of the area.

In the Kelowna area the upper portion of the great sedimentary

series has been completely eroded away, and only the deeper, highly granitized sediments remain. Erosion has reached such depth as to expose the higher parts of the undulating surface of an immense body of granite, which, judging by its wide distribution, underlies the entire region. The intimate association of granite with the gneisses is a very noticeable feature, not only in the Kelowna area but throughout the terrane.

The Nelson batholith underlies a wide area in the southern interior of British Columbia. In general all that can be said regarding its age is that it is post-Triassic. The granite in places forms a composite batholith, such as the Okanagan batholith described by Daly,[19] which is composed of two definite ages of granite separated by the Cretaceous. Farther north in the Okanagan valley two granites have been reported by Cairnes,[20] one late Mesozoic and the other Tertiary. Throughout large areas, if two ages of granite exist, there is no proof of such, since the composition of the granite of a single age may vary tremendously. According to Cairnes, the later granite is alkaline in character, and this proof of the age is its family resemblance to porphyry dikes and flows of definite Tertiary age.

At all events, it is generally agreed that the earliest known granite in the southern interior is Jurassic in age and that granite intrusion continued, perhaps intermittently, until well on in the Tertiary. The fact that some granite (presumably the earliest) penetrated only as far as the Beltian, whereas only a few miles distant laterally granite intruded rocks of Triassic age, a horizon several miles higher than the Beltian, suggests two distinct intrusions.

Dawson's admirable description of the Shuswap gneisses, which has been quoted by Daly,[21] applies equally well to the Kelowna area. The granite, which, in view of the facts given previously, is undoubtedly post-Triassic in age, bears the same intimate relationship to the gneisses here as elsewhere. Dawson mentions a sedimentary origin for part of the gneisses, but it should be stressed that the gneisses in

[19] "The Okanagan Composite Batholith of the Cascade Mountain System," *Bull. Geol. Soc. Amer.*, Vol. XVII (1906), p. 329.

[20] C. Cairnes, "Mineral Resources of Northern Okanagan Valley, British Columbia," *Geol. Surv. Can. Sum. Rept.* (1931), p. 69A.

[21] "A Geological Reconnaissance between Golden and Kamloops, British Columbia," *op. cit.*, p. 10.

general owe their structure to the original sedimentary formation, remnants of which remain. Where the bands can be traced considerable distances along their strike, and are uniform in thickness, it is fairly certain that they represent beds, even though hand specimens from any of the bands would give the prima facie impression of igneous origin. The criteria of uniformity in the determination of sedimentary origin have frequently been borne out by the presence of remnants of beds of quartzite or limestone.

The relative proportion of paragneiss to orthogneiss is not possible to determine accurately, for, although it is frequently possible to distinguish between them, many ambiguous cases are found, not only among the granitic types but also among the hornblendic. In places the gradation can be seen from gneiss to massive granite through the intermediate stage of foliated granite. Near the border of the massive granite no doubt exists of the igneous origin. Orthogneiss occurs also in the form of sills, and is recognizable by the lack of regularity, by the intrusive relationship of the bands one to another, and by inclusions. The inclusions are usually of the hornblendic phase of the gneiss, and usually possess a good cleavage. Where inclusions occur in relative abundance, there is an alinement of their long dimensions parallel to the foliation of the gneiss.

STRUCTURE

The foliation of the gneisses, in general gently dipping, follows no constant trend, though in any limited area of, for instance, a few square miles, it is quite constant. From observations of isolated exposures of gneiss in the great areas of heavily timbered uplands, little could be made of the structure, with the exception of the fact that the foliation runs in sweeping arcs across the country with a fine disregard for the trend of the Cordillera.

The gentleness of the flexures leads to the inevitable conclusion that lateral compression has played a very small part, if any, in the deformation of the gneisses, or in the deformation of the original rocks before they assumed their gneissic character. During the orogenic movements of the middle or late Mesozoic, when the Carboniferous and Triassic rocks of the plateau underwent considerable compression, resulting in comparatively tight folding in a northwest-

southeast direction, the gneisses either withstood these forces or were never subjected to them.

At this period the Beltian rocks were buried at a depth of 8–12 miles, and the granitic intrusions accompanying the orogenic disturbances granitized the more deeply buried strata. Daly[22] has suggested that the folding was confined to shallower depths, leaving the gneisses more or less undisturbed. No better explanation can be offered.

Okanagan Mountain, which was described by Dawson,[23] it is believed furnishes the key to the problem. The mountain is nearly a perfect example of what aptly has been termed "pine-tree structure." The granitized sedimentary bands, separated by orthogneiss sills, dip away from a central core of massive granite at angles averaging about 20°. The mountain, a "detached block of plateau country," is a fairly symmetrical dome, the topography of which is controlled by the geology, though the slopes are in general somewhat flatter than dip slopes. The topography in detail is rugged, owing to innumerable clefts which are thought to represent tension cracks of a fairly recent date.

The strata are roughly tangential to the core of massive granite which is exposed at the higher elevations; but the exact angular relationship is not ascertainable, because the massive granite of the core grades imperceptibly into foliated granite whose homogeneity is gradually lost by the presence in increasing quantities of hornblende rich bands, until the rock cannot be distinguished from the sill-sediment complex.

At the saddle where Okanagan Mountain joins the main upland mass, the Okanagan Mountain dome is in contact with a similar dome on a larger scale. As can be seen from the topography and from the radical changes in the strike of the foliation, the symmetry of the Okanagan Mountain dome is upset. Along this junction, marked by the two creeks which rise on opposite sides of the saddle, a greater irregularity in dip and strike of the strata than elsewhere exist; and, indeed, a crumpling might be expected between two such structures where they overlap.

[22] *Ibid.*, p. 53.

[23] "The Physical and Geological Features of the Southern Portions of the Interior of British Columbia," *Geol. Surv. Can. Rept. Prog., 1877–78*, p. 101B.

The presence of granite in the saddle at Chute Lake raises some doubt as to the isolated nature of the Okanagan Mountain dome. It may be regarded rather as owing to a lobe-shaped projection from

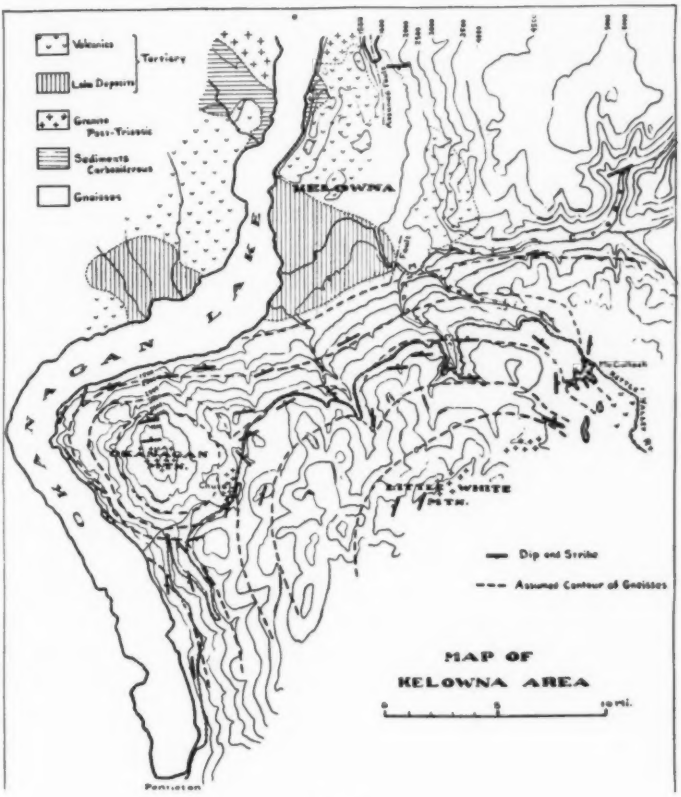

FIG. 3

a larger mass of granite which underlies the Little White Mountain upland.

The massive granite at Chute Lake, as elsewhere, grades into its foliated facies and gradually begins to show femic rich streaks and segregations, which bands become more and more pronounced far-

ther from the massive granite. Between this peripheral banded granite and the first outcrop of undoubted paragneiss, a gap of several hundred yards without an exposure exists, and the two rocks have an apparent angular discordance of as much as 60°. Whether this is their original relative attitude or whether the result of faulting is not known; but if the former is the case and the granite has cut the strata here, it adds support to the idea that the granite core of Okanagan Mountain is a lobe from a larger mass to the east, rather than an individual stock. Granite has necessarily penetrated the strata in some places to gain access to the interbed spaces.

On the extensive upland of which Little White Mountain forms the center, a domed structure similar to Okanagan Mountain exists. The core of the dome is exposed at the peak and for several miles northeast of it, and the massive granite shows a tendency to stand in fairly sharp relief above the surrounding gently contoured plateau. The gneisses dip quaquaversally at gentle angles. On the north flank of the dome local variations to the prevailing 15° northerly dip are found, in the line of a zone of faulting and folding which was observed in the lake deposits and lavas of Tertiary age of the Mission Creek basin.

The valley of Mission Creek in its east-west reach is somewhere near the limit of the Little White Mountain dome. In Mission Creek the strata are uniformly flatter than on the plateau, and the prevailing dip is still to the north. In the headwaters of Mission Creek, farther north, the dip is generally south, evidently beyond the influence of the Little White Mountain dome, and possibly on the flank of another dome the center of which has not been located.

THEORETICAL CONCLUSIONS

GENERAL

From the foregoing facts the following general conclusions are drawn concerning the manner of formation of the gneisses:

1. The original sedimentary rocks from which the gneisses are derived are probably low in the Beltian system, though not necessarily confined to it.

2. The depth of burial must have been at least 8 miles during Middle Mesozoic times.[24]

3. The temperature of the buried rocks must have been extremely high, even before their association with the granite.

4. The pressure, though it may have approached the hydrostatic condition at the time of the intrusion of the granite, could not have remained entirely so, because the injection of the granite necessitates differential pressure.

5. The movement of the granite magma *en masse* must have been very slow, however, since it caused the intruded rocks to yield principally by flow. The gentleness of the movement of the magma can be appreciated when one sees some of the delicate beds which have been arched but not broken.

6. The magma apparently experienced considerable difficulty in penetrating the strata, since the principal effect of deformation is a gentle doming of the strata, after the manner described by Van Hise.[25]

7. The magma did break through the strata, however, and the most vulnerable places in the sedimentary rocks were at the crests of domes, where they had been weakened by stretching. The Peak of Little White Mountain illustrates rather well the idea of a "plutonic plug" penetrating the strata at depth.

8. The actual manner of penetration can only be inferred. Three possibilities exist: (1) There may have been fusion of the invaded rocks. (2) The magma may have forcibly punched its way through. (3) Because of the elongation of the beds, owing to doming, and with a sudden pulsation of the magma, there may have been failure by tension.

9. The penetration of the strata by the magma gave it ingress to

[24] Estimated thickness of sediments in the Jurassic:

	Daly	*Dawson*	
Triassic	5,000	13,500	
Carboniferous	13,000	9,500	
Cambrian	7,000	40,000	(including Nisconlith and Adams Lake)
Beltian	32,750	.....	
	57,750	63,000	
	11 mi.	12 mi.	

[25] "A Treatise on Metamorphism," *op. cit.*, p. 708.

planes of weakness, and it found no difficulty in extending great distances parallel to the bedding, doming the strata still farther.

10. The highly tenuous solutions accompanying the granite magma, particularly that of the sills, thoroughly granitized the intersill rocks. The distribution of granitized rocks indicates that granitization did not progress great distances across the bedding, and it is only the immense number of sills that has rendered granitization so complete throughout so large a mass. The great number of pegmatites cutting these rocks testifies to the abundance of mineralizers accompanying the magma.

11. The most important conclusion to be drawn concerns the relations between cleavage and bedding—the problem in hand. This will be discussed in following pages. Briefly, the doming effect of the granite magma on the plastic strata caused their yielding by rock flowage, in which they were compressed in their short dimension and elongated parallel to their long dimensions. Thus the recrystallized minerals have an alinement parallel to the bedding. The schistosity was developed before the sills were injected, which gave more scope for the very intimate penetration of the sill injections, and hence for granitization. The lifting effect of the sills caused further doming, which increased the zone of schistosity.

ORIGIN OF THE FOLIATION OF THE KELOWNA GNEISSES

Van Hise[26] mentions three methods of intrusion of a magma of which the first, that of upwelling without breaking across the structures, is in this area the most important in its metamorphic effects, though perhaps not from the point of view of advancement of magma toward the surface. The reason for believing that this third method, fusion, plays an important part is the necessity of accounting for the disappearance of the pre-Beltian basement, upon which the Beltian series was laid. The presence of a large body of granite magma subjacent to a flat-lying sedimentary series at great depth can be explained best by fusion.

The first effect of the doming of the granite magma would be to compress the sedimentary strata, thinning the beds, and actually elongating them parallel to the bedding, since the plane of the bed-

[26] "A Treatise on Metamorphism," *op. cit.*, p. 708.

ding is deformed to a spheroidal surface. The amount of elongation will be appreciable, and roughly calculable. In one dimension it represents the difference in length between the arc of a circle and its chord, which in the case of Okanagan Mountain is about 2 per cent.

The strain ellipsoid must be placed with its short dimension normal to the bedding. It will approximate an oblate ellipsoid, but the axis the direction of which is down the dip will be slightly longer than the mean axis which will be parallel to the strike. In this position, parallel to the plane of maximum elongation of the rocks, schistosity will be developed.

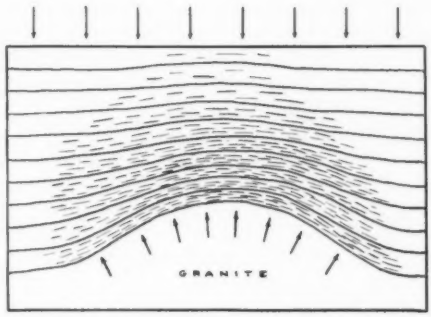

FIG. 4.—Doming: first stage. Simple dome rendering the strata schistose

When the granite magma had broken through the dome, it spread out readily along the planes of bedding and schistosity. When magma has the alternative of lifting the superincumbent beds directly, or effecting a gentler uplift by spreading laterally between beds, it appears to prefer the latter, whereby it gains a greater mechanical advantage by the principle of the hydraulic jack. The sills must necessarily have lifted the cover still farther, extending the dome and consequently the zone of schistose sediments and slate. The granitic injections parallel to the bedding and schistosity are so close together that, with the help of its complement of water and other mineralizers, the magma practically assimilated the intersill sedimentary matter. The original structure is inherited in the gneisses, but the former sedimentary rocks are now quite granitic, composed largely of feldspar, quartz, hornblende, and biotite, arranged with a dimension-

al parallel orientation. The addition of igneous material did not affect the manner of recrystallization, except in so far as the new minerals are predominantly of the non-platy type, quartz and feldspar, and the dimensional parallel orientation is not so conspicuous.

The sills, as well as the intersill strata, develop a dimensional orientation of their minerals parallel to the strata. In the larger sills this may be due largely to liquid flow, as suggested by the orientation of inclusions. This may not be the whole reason, however. The pressure of the magma from below must have continued after the lower sills were in place, in order to maintain the pressure at the feeders of higher sills which were formed later as the stock made its way upward.

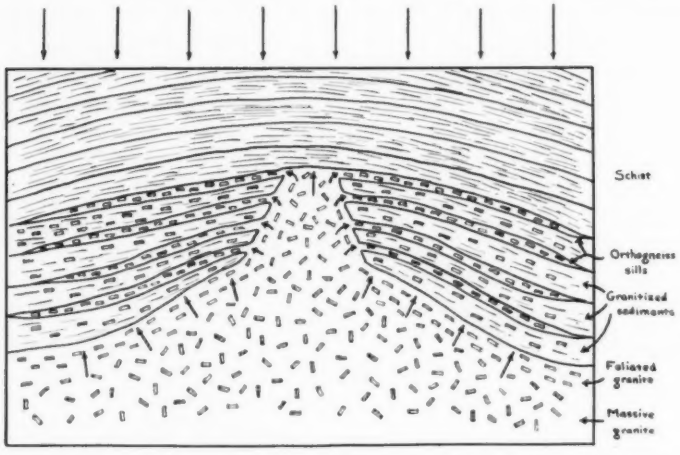

FIG. 5.—Doming: second stage. Granite penetrating crest of dome, injecting sills which granitize the intersill sedimentary material. The injection of the sills increases the doming effect in the cover, enlarging the zone of schists.

The peripheral foliation of the granite round the stock is attributable to the same causes as that of the sills. After cooling had commenced, currents parallel to the contact with the invaded rocks, like shore currents, would orient the minerals already crystallized. Although this will explain adequately the orientation, there is still the possibility, indeed probability, that after the margin had solidified,

the doming thrust from below continued, which would accentuate the foliation by recrystallization.

Van Hise,[27] discussing the metamorphic effects of a doming magma, says:

> It has already been indicated that as batholiths are intruded the rocks are deformed by being pushed aside. The deformation is mainly accomplished by recrystallization. . . . . During the process the majority of rocks take on a slaty or schistose structure. Cleavage developing normal to the pressure is peripheral to the batholith or circumscribes it. The contact effect naturally dies out as the distance increases from the intrusive. Near the intrusive the recrystallized rock may be a coarse-grained gneiss or schist; farther away from the intrusive it may become an ordinary slate; and still farther away a slaty cleavage may not be found unless it had been previously developed in some other way. Between these three zones there are gradations.

He refers to several typical examples in America, notably the Black Hills, the Carboniferous batholiths of New England, and the batholiths of the Rainy Lake district.

APPLICATION OF THE THEORY ON A REGIONAL SCALE

The Okanagan Mountain and Little White Mountain domes together occupy an area about 25×15 miles, which constitutes a small proportion of the Shuswap terrane. The question naturally arises: "Can this explanation be applied on a regional scale?"

In considering first what data there are on the Shuswap gneisses in general, it is necessary to refer again to G. M. Dawson,[28] who remarks:

> When the ruling lines of strike or foliation of the Shuswap are laid down, they are generally found to be parallel with each other in each particular region, but to run in great irregular sweeping curves over the face of the map as a whole, and sometimes to surround unfoliated granitic areas in a concentric manner, the whole appearance being very much like that met with in some parts of the Laurentian country in the east.

His map of 1898 of the Shuswap area illustrates this in places. Where this relationship is not seen, it is possible that normal faulting, which occurs in this region on a fairly large scale, has obscured it. Also, of course, the granitic cores in a large number of cases have not been uncovered by erosion.

[27] *Ibid.*, p. 716.

[28] "Geological Record of the Rocky Mountain Region in Canada," *op. cit.*, p. 64.

Referring specifically to the gneisses of Shuswap Lake and northeast of it, Dawson[29] mentions a gradation from rock of a bedded character toward massive, homogeneous, intrusive granite, which is presumed to exist in abundance along the axis of the Gold Range (Columbia Range), and he comments on the similarity of this structure to that of Okanagan Mountain. This phenomenon, he says,

> . . . . conveys to the mind the impression, that a plastic mass of granite may have been slowly pushed upward through the strata; rendering them also plastic on its approach, and reducing, to a great degree, the flexures with which they were already affected.

Dawson's section of this region[30] corroborates the idea of the doming habit of the granite.

FIG. 6.—Sketch section through Shuswap Lake, showing the probable arrangement of rocks. (After Dawson.)

Bowman's section[31] through the Cariboo area also suggests such a structure, though in his section the granite core is nowhere exposed. Elsewhere in the district oval areas of granite and granitoid gneisses are found which are suggestive of such a structure.

ORIGIN OF THE SCHISTOSITY OF THE BELTIAN

The sedimentary rocks and greenstones of the Shuswap Lake area are isolated from the principal Beltian section of the Selkirk Range by the broad expanse of gneisses. Throughout these sediments the schistosity is parallel to the bedding, with the exception of slight crumplings of a later date which are locally superimposed. The schistosity is not confined to the sedimentary rocks but is present also in great thicknesses of greenstones of volcanic origin, in which it is parallel to that of the underlying and overlying sediments. This precludes the possibility that the parting planes are inherent in the

[29] "The Physical and Geological Features of the Southern Portion of the Interior of British Columbia," *op. cit.*, p. 100B.

[30] *Ibid.*, p. 188B.

[31] A. Bowman, "Geology of the Mining District of Cariboo," *Geol. Surv. Can. Ann. Rept., Part III* (1887).

sediments, owing perhaps to a parallel arrangement of minerals in the original sedimentation.

In the area of the Kelowna domes, the cleavage of the less altered sedimentary rocks (fragmentary though they be) and the foliation of the paragneisses are manifestations of the same stresses, namely, the doming action of the granite. The resulting lateral relief would be felt beyond the zone penetrated by the granitizing juices. Which type of product results, schist or gneiss, depends largely on the availability of material to form the platy minerals, mica, hornblende, or chlorite. The overpowering predominance of felspathic material in the granite-soaked, intersill, sedimentary material, has made rather a rarity of schist in the region of the two domes described. Nevertheless, it does occur occasionally; and its metamorphism is similar to that of large areas of Beltian in that the cleavage is parallel to the bedding.

When large areas of sedimentary rocks are encountered, unaffected by the granitic juices, and having a well-marked cleavage parallel to the bedding, it is reasonable to apply this theory to account for their metamorphism, and to assume that their position stratigraphically was such that they were beyond the reach of granitization but that they were not beyond the effect of the doming.

To be convinced, however, that the schistosity parallel to the bedding in the Beltian sediments is due to the same cause as the parallel orientation of minerals in the gneisses, one has only to go to one of the localities where a mass of the meta-sedimentary rocks is in contact with the gneisses. The injection gneisses gradually fade out into meta-sedimentary rocks, with interlocking between the two types. Near the limit of penetration of the sediments by the granite magma and its juices, intersill beds exist which are slightly granitized adjacent to the sills, but schistose in the center. Farther toward the limit perhaps an isolated sill may be found between beds of metargillite. Beyond the last sill the bedding-schistosity is only interrupted by occasional beds of quartzite or marble which, because of their nature, are not rendered schistose.

Two such contacts—one on Albert Creek and the other Aberdeen Mountain—have already been described. Another is in Daly's Salmon Arm schists, where they grade up into the Sicamous formation

on Shuswap Lake north of Canoe point, and on the eastern peak of the Bastian Mountains.

Little progress has been made in working out the structure of the Shuswap Lake area, because of fairly intensive normal faulting which Daly[32] believes related to the secondary collapse of the mountain chain in its final gravitative adjustment following the relaxation of compression. The "homoclines" are structural units of fairly constant dip and strike, separated one from the other presumably by normal faults. Further difficulties in the way of working out the structure are the complete lack of distinctive horizons that can be used as markers, and the varying degree of intensity of metamorphism which may exist within one horizon. This area, therefore, is not very hopeful for the verification of the existence of domed structures in the sediments. There is nothing, however, opposing this idea.

Though evidence of doming in the railway section on Shuswap Lake is not likely to be obtained, surely it would be asking too much of coincidence to have two different causes for a regional parallelism of cleavage to bedding in two adjacent areas.

The Canadian Pacific Railway section from Shuswap Lake to the Selkirk summit may be a section of an enormous dome. The Beltian sediments on either side dip away from the underlying granitic gneisses, but the structure of this intervening mass of gneisses has not been worked out. Alternatively the homocline on either side of the mass of gneiss may represent a monoclinal block tilted by a thrust normal to the bedding by the subjacent magma.

OTHER CASES OF DOMING OF GRANITE

Some fine examples of doming of magma have been described, but the connection between doming and the parallelism of cleavage to bedding has not been emphasized. Alling[33] recognized doming as being one of three causes of foliation in the Grenville of the Adirondacks, the other two being (1) original bedding planes of sedimentary rocks and (2) secondary foliation of sediments. It is interesting to note that these three factors in the Kelowna area are coincident.

[32] "A Geological Reconnaissance between Golden and Kamloops, British Columbia, etc.," *op. cit.*, pp. 54–55.

[33] H. L. Alling, "The Origin of the Foliation and the Naming of Syntectic Rocks," *Amer. Jour. Sci.*, Vol. VIII (1924).

Holmes[34] describes a series of "inselberge" in Mozambique which appears to be a parallel case to the Kelowna domes. He says that the inselberge may owe their alinement to pressure tangential to the earth's crust, but that the peripheral gneisses owe their foliation to the shouldering effect of the granite.

The Rainy Lake district, described by Lawson,[35] offers such a perfect example of doming that it will be briefly reviewed. At Rice Bay, Coutchiching sediments, now largely mica schists, occur in an annular belt completely surrounding and dipping away from a central core of granite at angles of 40°–70°. A similar, though more gently contoured, dome occurs at Bears Passage. The Coutchiching series is now highly metamorphosed; and it includes, as well as mica schists, gneissic strata of sedimentary origin, and granitic sills related to the central mass. The schistosity is invariably parallel to the bedding. On this point he says:

> That we are dealing with bedding as well as schistosity in the observation of these dips is apparent from the usual evidence whereby the fact of bedding is established, viz., the contrasts of colour, weathering, texture, and composition of the different strata. The granitic core is foliated, also, and the foliation is parallel to that of the surrounding schists.

Regarding the deformation of the original sediments of the Rice Bay dome, he says:

> The dykes which traverse the schists transversely have been contorted due to a shortening in the direction of their strike, which has caused them to double on themselves in sigmoid curves, which are sometimes rather acute. The compression to which they have been subjected has very clearly diminished the width of the sills and the length of the dykes. The compression has without doubt similarly reduced the original thickness of the mica schists into which they are intrusive. The compensation for this reduction in thickness has been an elongation, chiefly in the direction of the dip, with a less marked elongation in the direction of the strike.

Much of this deformation Lawson regards as subsequent to the solidification of the granite. The steepness of the dips and the foliation of the granite he attributes to the later deformation. He does

[34] A. Holmes, "The Pre-Cambrian and Associated Rocks of the District of Mozambique," *Quar. Jour. Geol. Soc.* (1918), p. 31.

[35] A. C. Lawson, "The Archean Geology of Rainy Lake Restudied," *Geol. Soc. Can. Mem. 40* (1913).

not state the nature of these later stresses. But in order that the schistosity in the incompetent aureole of mica schists be preserved, and that the dip of the beds be steepened quaquaversally, the writer ventures to add that the causal force must have been a further shove from below, a further pulsation of the granite magma after the original schistosity of the sediments had been produced.

The age of the rocks in the area mentioned and also the relation of cleavage to bedding have been subjects of much discussion. But the later writers, Grout, Hawley,[36] and others, have not added to our knowledge of the domes, which are all that concern us here. In places in the so-called Coutchiching series, mapped by Lawson as extending far beyond the domes, these writers have found the cleavage making angles with the bedding, but Lawson's observation of the cleavage-bedding relationship within the domes is not questioned.

Adams[37] has a somewhat different idea as to the manner of formation of granitic gneisses of the Grenville, in Ontario, related to massive granite; but he confirms the doming habit:

> The granites well up through the Grenville sediments in the form of batholiths of the same type as those described many years since by Lawson in the Lake of the Woods region some 900 miles further west along the margin of the same protaxis. The slow upward movement of the granite which took place while its cooling and crystallization were going forward, gave rise to a protoclastic structure in the granite, resulting in a primary gneissic structure due to the movement in the cooling and crystallizing magma, which structure conforms to all the sinuosities of the outlines of the mass. To this outline or border also the strike of the penetrated sediments conforms, and as the latter become more disintegrated in character and smaller in amount, they form long sinuous remnants whose course always follows the strike of the foliation of the gneissic granite and which eventually are dissipated as inclusions in it.
>
> The granite intrusion had a very slow movement, as shown by the fact that the movement, beginning when the magma was still uncrystallized continued while it was crystallizing, during the time it was filled with the products of crystallization and until it finally became solid. As it lifted the cover of the pre-Cambrian sediments into which it was rising, it did so in a somewhat uneven manner, the sedimentary cover rising in gentle, dome-shaped arches and in the

[36] F. F. Grout, "Coutchiching Problem," *Bull. Geol. Soc. Amer.*, Vol. XXXVI (1925), p. 351; J. E. Hawley, " 'Seine' or 'Coutchiching'?" *Jour. Geol.*, Vol. XXXVIII (1930), p. 521.

[37] F. D. Adams, "The Origin of the Deep-seated Metamorphism of the Pre-Cambrian Crystalline Schists," *Compte Rendu du XI^e Cong. Geol. Int.*, 1911, p. 565.

intervening areas sinking into sinuous troughs, the foliation of the gneiss being, as has been mentioned, a primary structure, following all the sinuosities in the strike of the eroded sedimentary cover.

Miller,[38] in describing the Grenville gneisses of New York, remarks on the lack of severe folding. The intrusive action involved a tilting, lifting, or doming of the intruded sediments. The parallelism of cleavage to bedding he ascribes to load metamorphism because of the open folding. In this regard he quotes Van Hise: "Vertical shortening and consequent elongation below the level of no lateral stress may have begun the process."[39] Miller adds that this is essentially the whole process. The present writer is inclined to think that the doming theory might be applicable here too.

Mennell[40] cites other instances of doming in Africa.

In almost every case of metamorphism which has been ascribed to load, granite is present in close association. Monoclines or gentle, open folds are the characteristic structures, and doming is quite common.

Daly[41] gives a list of ten examples of load metamorphism, apart from his classic exanple of the Shuswap terrane. In five cases granite is present in close association; and in all cases granitic gneisses exist, variously termed "injectiongneis," "eruptivgneis," etc., and the presence of granite is assumed because of granitization, or the presence of pegmatite dikes. The association of granite and granitized rocks with rocks showing cleavage parallel to bedding must be more

[38] W. M. Miller, "Origin of Foliation in the Pre-Cambrian Rocks of Northern New York," *Jour. Geol.*, Vol. XXIV (1916), p. 587.

[39] "Principles of North American Pre-Cambrian Geology," *U.S. Geol. Surv., 16th Ann. Rept.*, Part I, p. 773.

[40] F. P. Mennell, "Some Notes on Archean Stratigraphy," *Geol. Mag.* (1906), p. 256.

[41] "Metamorphism and Its Phases," *Bull. Geol. Soc. Amer.*, Vol. XXVIII (1916), p. 402.

Alps: Lory, Granite assumed because of granitization.
Labrador: Low, Granite and granitic gneiss present.
Adirondacks: Cushing, Miller, Granite present.
Greenland: Heim, Granitic gneisses and pegmatites present.
Waldviertel: Beck, Granitic injection gneisses present.
Erzgebirge: Lepsius, Dome of gneisses with granite core.
Schwartzwald: Schwenkel, "Eruptivgneise."
Oban-Dalmally: Kynaston, Intrusives, epidiorite.
German East Africa: Schmidt, No details given.
Rhodesia Congo, Etc.: Mennell, Granite present.

than a coincidence, and the writer suspects that the doming theory may be applicable in at least some of these cases.

The universal association of granite with regionally metamorphosed rocks is very striking, a fact which has been emphasized by Termier,[42] Barrell,[43] Hogbom,[44] and Sederholm.[45]

SUMMARY AND CONCLUSIONS

The rocks of the Shuswap terrane are characterized by a parallelism of cleavage to the sedimentary stratification over wide areas. The gentleness of the dips and the absence of evidence of orogenic movements gave rise to the idea that the weight of the overlying beds was responsible for the metamorphism which produced this parallelism. The chief objection to this explanation is that, if load were the only force acting, the pressure on rocks at depth would be hydrostatic; and deformation resulting from cubic compression cannot produce an alinement of minerals.

A study of the structure of the gneisses reveals a common habit of a quaquaversal arrangement round granite stocks. Thus there is evidence of another force besides load, namely, an upward thrust of the granite magma which has domed up the strata. The sediments have yielded by rock flowage, and have been shortened normal to the bedding and elongated parallel to it. The arrangement of minerals in the resulting schists is in the direction of easiest relief, which is parallel to the bedding.

This explanation applies both to the Shuswap gneisses and to the overlying Beltian meta-sedimentary rocks (though in the case of the orthogneiss the cleavage may be in part due to primary igneous flow). The essential difference between the metamorphism of the gneisses and that of the schists lies in the abundance of material from igneous sources in the former case and the lack of it in the latter.

[42] P. Termier, "Relations of Subjacent Igneous Invasion to Regional Metamorphism," *Compte Rendus XI^e Cong. Geol. Int.*

[43] J. Barrell, "Pre-Cambrian Geology of Sweden," *Amer. Jour. Sci.*, Vol. I (1921), p. 3.

[44] A. G. Hogbom, "Pre-Cambrian Geology of Sweden," *Bull. Geol. Inst. Upsala*, Vol. X (1909).

[45] "On Granite and Gneiss," *Bull. Geol. Comm. Finland, No. 23* (1907); "On Synantetic Minerals," *ibid., No. 48* (1916); *op. cit., No. 58* (1923); *ibid., Part II, No. 77* (1926).

Granitization of the sediments adjacent to the granite occurred on a large scale when the magma penetrated the strata at the crests of the domes. On obtaining access to the planes of schistosity and bedding the magma was enabled to mingle intimately with the sediments. The schistose sediments of the Beltian overlie the gneisses conformably, but with an interlocking relationship. They lie above the zone of penetration of the granitizing solutions, yet within the zone deformed by the doming effect of the granite.

This type of metamorphism cannot be made to fit into Daly's classification of metamorphic processes.[46] Since it is due to deformation caused by an active thrust of a magma at depth, it cannot be regarded as static, nor can it be regarded as due to orogenic movement in its usual sense. Conforming with the prevalent use of the term "dynamic metamorphism" as synonymous with "rock flowage," the metamorphism of the rocks of the Shuswap terrane is definitely dynamic.

[46] "Metamorphism and Its Phases," *op. cit.*, p. 408.

AMERICAN CARBONIFEROUS DIPNOANS

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ABSTRACT

New Carboniferous lungfish material is described and figured, including *Prosagenodus? castrensis* sp. nov., founded on a tooth plate from the Chester; a skull roof from the Pennsylvanian of Illinois assigned to *S. serratus;* a tooth from the same period and region described as *Proceratodus carlinvillensis*, gen. et sp. nov.; and *S. ciscoenis* sp. nov., from the summit of the Cisco of Texas. *Prosagenodus* gen. nov. is proposed, with *Ctenodus interruptus* Barkas as genotype. The North American Pennsylvanian and Permian dipnoans are reviewed.

INTRODUCTION

This article owes its inception to the presence in Walker Museum, University of Chicago, of several lungfish specimens worthy of description. In the course of study of this material it was found necessary to re-examine the previously described dipnoans of the Carboniferous and Permian of North America. Some two dozen species have been described, most of them from very scanty material. A discussion of these earlier finds seems desirable in the light of present knowledge.

The literature on North American dipnoans is readily accessible in Hay's excellent bibliographies of vertebrate paleontology and therefore detailed citations of the earlier papers on the subject are unnecessary. We are greatly indebted to Dr. E. C. Case, of the University of Michigan, Dr. H. H. Lane, of the University of Kansas, and Dr. W. K. Gregory and Miss F. F. la Monte, of the American Museum of Natural History, for the loan of material.

A DIPNOAN TOOTH PLATE FROM THE MISSISSIPPIAN

No remains of dipnoans have been reported hitherto from rocks of Mississippian age in North America, unless some of the material from Warren, Pennsylvania, described by Newberry should prove to be early Mississippian rather than "Chemung" in age, or unless the Cleveland shale be ascribed to this period. The tooth plate illustrated in Figure 1 is hence of some interest. The tooth was found in the Chester limestone in the vicinity of Chester, Illinois, embedded

in an impure limestone containing fragments of corals and other invertebrates. The extreme length is 24 mm. Nine ridges are present, separated by deep grooves distally and with the more anterior grooves extending through to the median edge of the tooth. Both the ridges and the grooves between them are convex in cross section, suggesting that a "splenial" plate is being dealt with, although one of a much flatter type than in typical members of *Sagenodus*. The tuberculations are well marked, particularly the more distal ones, and those of the more anterior ridges, which are separated from one another by deep clefts. The most anterior ridge is not only considerably longer than the next following but is higher throughout. The ridges are nearly straight, in contrast to the curved condition usual in the case of the more anterior and posterior ridges in *Sagenodus*, and radiate from a common point on the strongly angulated internal margin of the tooth. The tubercles, particularly on the more anterior ridges, are markedly thin from side to side, in contrast with the stouter tubercles in such Pennsylvanian plates as are available to the writers. The distal tubercles are vertically directed, with none of the outward inclination seen in many Pennsylvanian plates.

FIG. 1.—Type tooth plate of *Prosagenodus castrensis* sp. nov., from the Chester series (Mississippian), Chester, Illinois. (Gurley Collection, Walker Museum, No. 12245.) Natural size.

Both stratigraphic position and the characters previously noted warrant the erection of a new species for this specimen. The question of generic assignment, however, is not clear. This plate is more primitive in a number of features than any specimen of *Sagenodus* with which we are familiar, and seems transitional between the *Dipterus* type and the genus *Sagenodus*.

"*Ctenodus*" *interruptus* of the Mississippian of England, as described by Smith Woodward, Traquair, and Watson and Gill,[1] appears to present points of similarity, particularly in the compression of the tubercles, although the only illustrated specimens of that form do not have the marked angulation of the inner margin found in the present specimen.

[1] "The Structure of Certain Paleozoic Dipnoi," *Trans. Linnean Soc.*, London, Vol. XXXV (1923), p. 192, Fig. 24.

This European type does not fall into any recognized genus, combining (as Watson and Gill have noted) a *Ctenodus* skull pattern with tooth plates of *Sagenodus* type. Not improbably it lies close to the point of divergence of these two genera. The writers propose that it be considered, as the type of a new genus, *Prosagenodus*, characterized by the combination of the characters mentioned. To this genus would be referred provisionally the tooth plate here described, as *Prosagenodus? castrensis* sp. nov.

CTENODUS IN THE AMERICAN CARBONIFEROUS

Tooth plates of the true *Ctenodus* type, characterized by great breadth and numerous parallel tuberculated ridges, seem to be not uncommon in the European Coal Measures. On this continent many forms now properly assigned to *Sagenodus* were originally described as *Ctenodus*, and even the latest English edition of Zittel[2] states that *Ctenodus* dental plates are common in North America. In point of fact, they are exceedingly rare in the American Carboniferous. Only two specimens which properly seem assignable to this genus are recorded. In 1868 Dawson described an imperfect tooth plate from the Joggins of Nova Scotia as *Conchodus plicatus*. As Smith Woodward has noted, this appears to be an abraded tooth plate of *Ctenodus*. In 1903 Eastman described, as the only tooth plate known from the Pennsylvanian of Mazon Creek, Illinois, *Sagenodus cristatus*. The specimen as preserved shows seven parallel coarsely tuberculated ridges. Eastman compares this with *Ctenodus*, and it seems certain to us that the specimen is actually an imperfect tooth plate of that genus.

The Mazon Creek beds are at a rather low horizon in the Pennsylvanian (Lower Carbondale, about Middle Allegheny); the stratigraphic position of the Joggins is not clearly established. It is possible that the lack of remains of *Ctenodus* in other and later deposits is due to an early extinction of this genus in North America.

MAZON CREEK LUNGFISH SCALES

Among the fish remains from the famous Pennsylvanian plant-bearing nodule beds of the Mazon Creek–Braidwood region of Illinois, impressions of scales of lungfish are not infrequent. Some nine

[2] K. A. Zittel, *Textbook of Paleontology*, Vol. II (2d ed., 1933), p. 102.

species have been described, including "*Rhizodus*" *occidentalis*, Newberry and Worthen 1866, "*Rhizodus*" *reticulatus*, Newberry and Worthen 1870, and the following seven species, all described by Cope in 1897: *Sagenodus browniae*, *S. conchiolepis*, *S. foliatus*, *S. gurleianus* (renamed *S. textilis* by Hay in 1899), *S. lacovianus*, *S. magister*, and *S. quincunciatus*. All these species are now generally assigned to *Sagenodus*.

Superficially, it would seem highly improbable that nine species of the same fish genus should have lived side by side in a restricted area during a short time interval under apparently uniform environmental conditions. Hay suggests that these various forms may have been carried down to the Mazon Creek deposits from a number of converging river systems, but this is rather far-fetched. All these "species" are founded on isolated scales. The type descriptions and the extensive redescription by Hay in 1900 distinguish between species almost exclusively on the basis of the varying shape of the scales and on variations in their reticulations and striations. These features, however, are quite certainly not such as to be of much value in distinguishing between lungfish species, as Hay in part admits. The twelve scales shown in Figure 2 were taken by the writers at random from various areas of the body of a single specimen of the living lungfish *Epiceratodus*. If these scales be compared with those figured from Mazon Creek by Newberry and Cope, it will be seen that, although from a single individual, they exhibit as great a diversity of form as the "species" from Mazon Creek, and the variation in markings also appears to be as great in these twelve scales as in the fossil types discussed. There is nothing to show that the Mazon Creek scales may not have all pertained to a single species; indeed, it is not impossible that several "species" might have come from a single cadaver. All that the descriptions of the Mazon Creek fossils tell us is that lungfish were present in the beds there. *S. occidentalis*, as the first described type, may well stand; but since no adequate

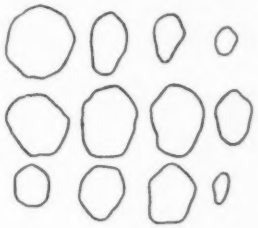

FIG. 2.—Outlines of a series of scales taken at random from a specimen of *Epiceratodus forsteii*, to show the variations in a single individual.

distinguishing features appear in the descriptions of the remaining species they should be relegated to the synonymy.

This situation is but one example of the plethora of specific names in vertebrate paleontology. Of the ten thousand or more described North American species, many based on very fragmentary material, probably half or two-thirds at least would be found to be synonyms were we fully conversant with them. Many of these names, even when based on very poor material, have served, and do serve, a useful purpose in calling attention to the existence of seemingly new or problematical forms, or to the existence of known genera in fresh horizons or regions. On the other hand, we believe that not even the most conservative systematist can object to the following proposition as a useful working rule: that if, from a given horizon and region, one species of a genus has been described, no further species of that genus should be named unless the specimens found exhibit one or more characters which might reasonably be expected to distinguish them from the first; and that if, in the absence of presumably valid differences, further species are named, they should be regarded as synonyms of that first described from the horizon and locality.

SAGENODUS REMAINS FROM LINTON, OHIO

Lungfish remains are not uncommon in this famous cannel coal deposit, of uppermost Allegheny age (Upper Freeport coal), from which have come a majority of known American Carboniferous amphibians. In 1916 Hussakof summarized our knowledge of Linton dipnoans. We again meet with a multiplicity of names. *Eurythorax sublaevis* was established by Cope in 1871 on the basis of an operculum; Newberry described "*Rhizodus*" *quadratus* in 1873 on the basis of scales and "*Ctenodus*" *serratus* on tooth material in 1875; and Cope in the same volume of the geology of Ohio described "*Ctenodus*" *ohioensis* on the basis of a skull roof. Taken together, these remains show that one or more lungfish of the *Sagenodus* type were present, but show little else. There is no overlap in any Linton specimen between the four types of material—scales, operculum, cranial roof and teeth—upon which these species were established.

The type of *Eurythorax sublaevis* is a lungfish operculum, described and figured by both Cope (who thought it pertained to an amphib-

ian) and Hussakof. The name is, the writers believe, to be regarded as a *nomen nudum*. Watson and Gill in their study of British Carboniferous lungfish[3] have pointed out that in the typical Carboniferous genera the operculum exhibits no characters of generic, not to mention specific, value. Hussakof has compared this operculum with those from Bohemia figured by Fritsch; there are said to be differences in "minor details," which he seems, however, unable to define. We have compared the specimen with the only other known American operacula, those from Kansas and Peoria; the plate, except for size, agrees well with that of both of the two species represented. Since this specimen does not and apparently cannot furnish us with any possible character on which to base a specific definition, *Eurythorax sublaevis* is considered a *nomen nudum*.

Sagenodus (*"Rhizodus"*) *quadratus* of Newberry is based on scales. The problem of species based on such material has been commented upon on foregoing pages. It is highly improbable that these scales can ever be correlated with other types of lungfish material, but since the species was described at an early date and is the only Linton species described from scales, there is less reason to regard this name as invalid than in the case of the Mazon Creek species.

Sagenodus (*Ctenodus*) *serratus* was described by Newberry on the basis of a palatal tooth plate, which he figures, showing eight ridges with well-separated and sharp tuberculations. Hussakof later figured a squeeze from the reverse of this specimen. This squeeze gives a misleading appearance in that the ridges appear to be less developed and the denticulations less clearly marked than they originally were in the positive figured by Newberry.

"Ctenodus" reticulatus,[4] described by Newberry as a presumed dental plate, is stated by Hussakof to be indeterminate, and may pertain to an amphibian rather than to a lungfish.

S. (*Ctenodus*) *ohioensis* was described by Cope on the basis of the greater part of a cranial roof. Newberry assigned a second specimen to this species (this is redescribed by Hussakof) and a third imperfect specimen of lungfish skull roof from Linton described by Watson and Gill may be specifically identical. The Cope and New-

[3] *Op. cit.*, p. 193.

[4] Hay in 1900 renamed this form *S. jugosus*.

berry specimens are of considerable size (Watson and Gill give no measurements). The "parietal" (of Watson and Gill's nomenclature) is comparatively narrow; the "frontals" are very large and broad; in the specimens described by Cope and Newberry and on one side of that described by Watson and Gill a particularly striking feature is the absence of the "intertemporal" or its fusion with the "supratemporal" element.[5] This last feature is very probably of specific value, and is not found in the only other known American Carboniferous skull roof, described in this article. The Cope and Newberry specimens are too large to be associated with the type tooth plate of *S. serratus* from the same locality, and *Sagenodus ohioensis* seems to be a valid species.

There are thus definitely at Linton two species of *Sagenodus*—*S. serratus*, based on a tooth plate of modest size, and *S. ohioensis*, considerably larger, known from cranial roof material. The other Linton fragments pertaining to "normal" lungfish types (operculum, scales, ribs) cannot be definitely assigned to either of these.

SAGENODUS FROM THE PENNSYLVANIAN OF DANVILLE, ILLINOIS

A series of vertebrate remains discovered by W. F. E. Gurley in the valley of the Vermilion River near Danville, Illinois, was described by Cope in 1875 and later years, and redescribed by Case in 1901, and (as regards fishes) by Hussakof in 1911. This material is now part of the Gurley Collection in Walker Museum. Cope regarded the horizon as Permian, and correlated the finds with those from the Texas Red Beds discovered shortly after. The sediments of this region in general have been regarded as Pennsylvanian in age. Some have thought that this bone bed may represent a Permian stream-channel fill in older rocks, whereas others have thought that the supposed Pennsylvanian strata of the region may be really Permian in age. Drs. J. Marvin Weller and H. R. Wanless, however, inform us that the bed is Pennsylvanian (Middle McLeansboro, about Lower Conemaugh) in age.[6] The Danville vertebrates

[5] Possibly two of these three specimens may belong to the same individual. The collector(s) of the Linton material are known in other cases to have so distributed the material that, for example, the obverse of one amphibian skull is in New York, the reverse, in the British Museum.

[6] The geologic data are to be published elsewhere by H. R. Wanless.

are thus Pennsylvanian, rather than Permian; this is consistent with the writers' findings in Texas and other areas, namely, that the "Permian" vertebrate fauna extends downward into Pennsylvanian rocks.

Six species, described by Cope from Danville, each founded on the basis of a tooth plate, or a portion of one are now generally recognized as belonging to the genus *Sagenodus*. These include *Ceratodus vinslovii* (1875), *Ctenodus gurleyanus*, *Ctenodus fossatus*, *Ceratodus paucicristatus* (1877), *Ctenodus vabasensis*, and *Ctenodus heterolophus* (1883).

The type of *S. heterolophus* is lost; the description, based upon a fragment of a tooth plate, gives no adequate distinction from other *Sagenodus* tooth plates (particularly if the anterior ridge were absent), and the species is indeterminate. Hussakof, in his redescription of the lungfish material in 1911, regarded *S. vabasensis* and *S. gurleyanus* as synonyms of *S. fossatus*. The type of the last is an incomplete and somewhat worn mandibular plate of moderate breadth, with well-marked tuberculations. Distally the tips of the ridges curve sharply downward to present an outer face two-thirds as long as the dorsal margin of the ridges. Seven ridges appear to have been present. The type of *S. vabasensis*, well-figured by Hussakof, is a nearly complete upper plate of appropriate size and construction. Seven radiating ridges and a small posterior "heel" with two incipient ridges are present. Tubercles are visible over most of the length of the ridges. The more distal tuberculations are separated by deep clefts and are directed outward to a moderate degree (Fig. 3*a*). The first ridge is very low proximally, but (although incomplete) appears to have been much longer and higher distally than the second. The type of *S. gurleyanus*, a small and imperfect tooth plate, is somewhat more doubtfully referable to the species.

S. vinslovii is retained as a separate species by Hussakof. The type is an imperfect palatal plate. His main bases for distinction from *S. fossatus* rest upon features such as the obliteration in great measure of the tubercles which are obviously due to the much-worn condition of the plate. The contour of the plate is very similar to that of *S. fossatus*, and there is evidence of seven ridges, not six as stated by Hussakof. An additional specimen in the Gurley collection is a

moderately worn palatal plate which completely bridges the gap between the types of *S. vinslovii* and *S. fossatus*. *S. vinslovii* is thus also synonymous with *S. fossatus*.

If the tooth of "*S. vabasensis*," included in the above synonomy, be compared with Newberry's figure of the type of *S. serratus* from Linton, it will be seen that the two are indistinguishable. Hussakof, in his 1916 discussion of the Linton material, says that *S. serratus* differs from the Danville specimens "in the ridges being less developed and the denticulation not so plainly marked." But these supposed differences are based on the squeeze of the *S. serratus* type,

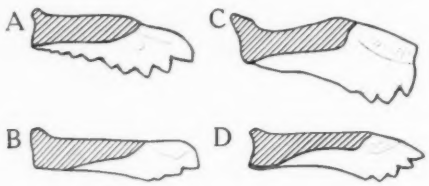

FIG. 3.—Semi-diagrammatic cross section through the palatal tooth plates of various species of *Sagenodus*, to show the contour of the coronal surface and the type of tuberculation. The section is taken as if through the valley posterior to the second ridge, which is figured; the palatal surface downward. Not to scale.

A, *S. serratus* (from the type of *C. vabasensis*); *B*, *S. periprion* (University of Michigan, No. 3055); *C*, *S. porrectus* (University of Michigan, No. 15444); *D*, *S. ciscoensis* (Walker Museum, No. 2204).

not the specimen itself, which Newberry's figure shows to be well tuberculated. The Linton and Danville horizons are apparently not widely separated chronologically, and in default of any distinctive features the Danville material is to be regarded as pertaining to *S. serratus* as the species first described.

One Danville specimen appears, however, to belong to a distinct species. This is the type of *S. paucicristatus*, consisting of a partial mandibular plate. It has been adequately illustrated by Hussakof. The plate is badly worn and with little trace of tuberculations remaining. It is a long, narrow type quite unlike *S. serratus;* its affinities seem to lie with *S. copeanus* and *S. porrectus*, described in following paragraphs.

A SKULL ROOF OF SAGENODUS SERRATUS

Cranial material of *Sagenodus*, not uncommon in the Pennsylvanian of Europe, has been represented hitherto in this country only by the Linton specimens previously noted and isolated elements from Kansas associated with *S. copeanus*. The specimen here described is part of the Gurley Collection, Walker Museum, and is recorded as found associated with "coal No. 4" (Lower Carbondale group) near Peoria, Illinois. It is represented by impressions on slabs of cannel of both dorsal and ventral aspects of the greater part of a skull roof and part of a lower jaw and by a part of the actual osseous material of the skull elements.

The specimen is shown in Figure 4 and need not be described in detail. If compared with the "typical" European specimen of *Sagenodus* figured by Watson and Gill,[7] it will be noted the elements are almost identical in proportions and interrelations, as regards the ventral aspect; on the outer side, however, the "parietal" (of Watson's nomenclature) overlaps the "interfrontal" to a considerable extent and is widely overlapped by the "tabulars"; it thus appears to be a much longer and narrower bone than when seen from below. The "intertemporals" have a much smaller exposure dorsally than ventrally. A notable feature is the presence of conspicuous grooves for sensory canals. A well-developed groove for the transverse occipital lateral line canal crosses the most posterior series of cranial elements. From the end of this groove a channel, presumably containing a continuation of the main lateral line canal, passes forward onto the "squamosal," thence medially onto the "frontal" and from there forward, apparently onto a marginal lying lateral to the "nasal." The line of the canals passes in great measure between the centers of ossification of the several bony elements. The groove reported by Watson and Gill as connecting "parietal" and "squamosal" and present in several other dipnoan genera is not evident.

As far as the writers are aware, the element identified as "frontal" by Watson and Gill in other genera does not carry the supraorbital canal; this passes forward along a series of more lateral elements. Perhaps the element in question in *Sagenodus* is not homologous with

[7] *Op. cit.*, Fig. 1.

the similarly termed element in *Dipterus*, *Scaumenacia*, or *Ctenodus*, but with an enlarged "postfrontal," the "frontals" having succumbed to the encroachments of the growing median elements.

An incomplete operculum is present. A few inches from the skull is the right jaw ramus bearing a tooth plate, both truncated by the margin of the slab. This tooth, as far as preserved, appears to be indistinguishable from a lower plate from the Danville locality, the

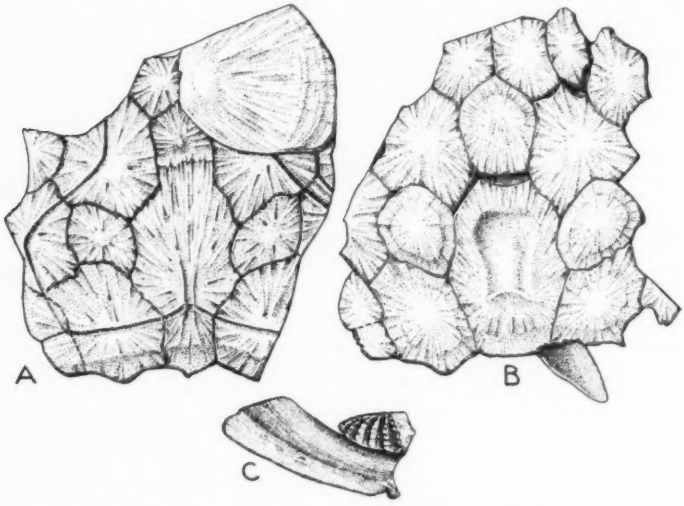

FIG. 4.—Skull roof assigned to *S. serratus*, from the Pennsylvanian of Peoria, Illinois. *A*, dorsal surface; *B*, ventral surface (reversed); *C*, incomplete jaw and attached tooth plate.

type of *S. fossatus;* and this in turn the writers have noted to be presumably cospecific with *S. serratus*, to which species is, therefore, ascribed this skull.

After the preceding identification was made, it was found that this specimen had also been identified by Newberry as pertaining to *S. serratus*. The writer's specimen is obviously distinct from the (much larger) skull roofs from Linton described by Cope, by Newberry and Hussakof, and by Watson and Gill, particularly as regards the apparent suppression of the "intertemporal" in *S. ohioensis*.

SAGENODUS IN THE KANSAS COAL MEASURES

Sagenodus copeanus of Williston, from the late Pennsylvanian (basal Waubaunsee) of Brown County, Kansas, is represented by fragmentary cranial plate material suggesting a typical *Sagenodus* pattern, as well as a number of dental plates and their supporting bony elements. The narrowness of the plates suggests a comparison with *Sagenodus porrectus* of Texas. The last, however, has one or two ridges less per tooth and in the only specimen of *S. copeanus* in which the distal end of the ridges of the palatal plate are seen, the terminal tubercles are directed outward, rather than downward as in *S. porrectus*. The orientation of the ridges is quite different from that observed in *S. periprion;* the tooth plate shape is quite different from that of *S. ciscoensis*. From *S. serratus*, as exemplified by the type of *S. vinslovii* of Danville, the differences lie in the seeming absence of the tuberculations on the proximal portion of the ridges and the narrower proportions of the tooth plate. This species is obviously close to *S. paucicristatus* of Danville. Both are of the elongated, narrow type. The second ridge of the only known *S. paucicristatus* specimen is, however, considerably longer than that found in the two examples of the lower plate of the Kansas form and the two may be kept distinct for the time being on the basis of this feature.

SAGENODUS IN THE PERMIAN OF TEXAS

Three species properly pertaining to this genus were described by Cope in 1878 on the basis of dental plates from the Permo-Carboniferous of Texas—*S. dialophus*, *periprion*, and *porrectus*. Although no record of exact locality exists it is probable that, like most of the material collected at that time, they were from the Wichita group, lowermost Permian. These three species seem to be valid and almost all the further material of *Sagenodus* from the Texas Permian seems to fit well into one of the three.[8] The type material has been figured by Hussakof in 1911.

S. dialophus is mainly characterized by a larger number of tooth ridges than are found in any other member of the genus. Although other specimens of this species are found in the collection of the American Museum, University of Michigan Museum, and Walker

[8] A specimen from an earlier Texas horizon is described below.

Museum, no one is complete; probably about 15 ridges were present in life.

Such a considerable ridge count suggests a reference to *Ctenodus*, of which this feature is a characteristic. But the *Ctenodus* plates are broad and coarsely tuberculated, which are features not seen in *S. dialophus*. Presumably the increase in ridges is merely a parallelism; this form may well have been derived from such a form as *S. serratus* of the Pennsylvanian.

S. periprion was described on the basis of a palatal tooth, incomplete posteriorly. The straightness and the forward inclination of all the ridges preserved in the type are distinctive features. Two further specimens, showing the anterior palatal ridges, are present in the University of Michigan collections. One of these (Fig. 5*a*) which is little worn, seems to show that the tuberculations were in great measure confined to the distal end of the ridges. These distal tuberculations are very distinct, and directed strongly outward (Fig. 3*b*). The most anterior ridge, though higher distally than those behind it, does not rise above the general level of the tooth plate until the tuberculated region has been nearly reached. We have seen no "splenial" plates which can be assigned to this distinctive species.

The third species, *S. porrectus*, was described from a palatal plate.[9] A number of other Wichita specimens appear to be in agreement with this type, including a nearly complete although considerably worn palatal plate in the University of Michigan collections (No. 15444, Fig. 5*d*), a similar specimen in Walker Museum (No. 1107), and a nearly complete lower tooth plate and splenial in Walker Museum (No. 1105, Fig. 7*a*). Seven tooth ridges are present above and below. The plates, particularly the "splenial" ones, are comparatively narrow. The most anterior ridge is very much longer than those behind it on the only "splenial" tooth in which it is preserved. No tuberculations are shown on the proximal portion of the ridges in any specimen known to us. The short posterior splenial ridges run outward with their upper edges approximately in a plane with the inner margin of the tooth; distally they drop downward to a depth nearly as great as the width of the tooth plate. The depth of the lower ridges, the prominent downward projecting distal

[9] Cope's type was from Texas, not Illinois as Hussakof states.

portions of the upper ridges, the deep clefts between ridges with a resultant narrowing of the plate proper, and the considerable reduc-

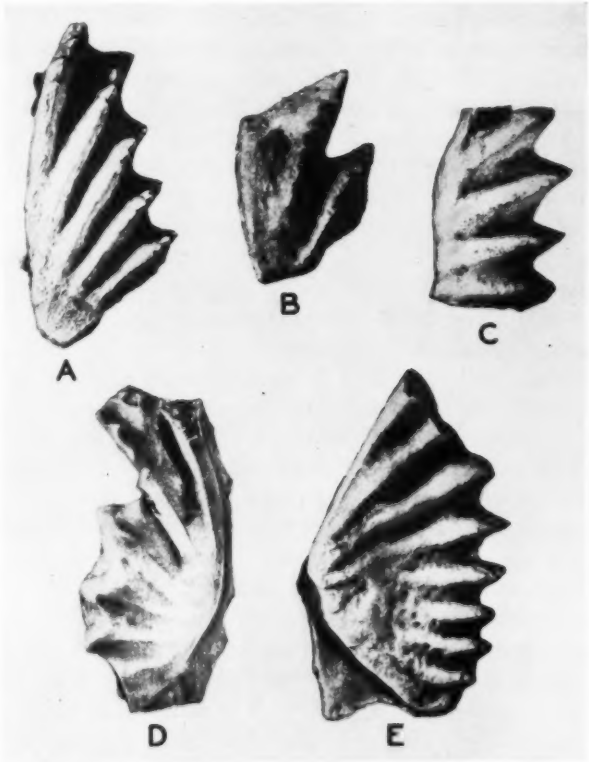

FIG. 5.—*A*, Anterior portion of pterygoid tooth plate of *S. periprion* (University of Michigan, No. 3055). *B*, Portion of unworn tooth plate of *S. ciscoensis*. *C*, Portion of lower plate of the same. *D*, Pterygoid tooth plate of *S. porrectus* (University of Michigan, No. 15444). *E*, Pterygoid tooth plate of *S. ciscoensis;* worn, distal ends of the first two ridges absent. (*B*, *C*, *E*, No. 2204, Walker Museum, co-types.) All ×1.

tion of the tuberculations on the proximal portion of the ridges suggest that in this species we perhaps are not far from the point of origin of the line leading to the existing *Epiceratodus*. Whether,

however, *Ceratodus* proper has had a like origin seems to us more than doubtful. In this last genus the tendency seems to be toward the retention of a broad crushing plate and lack of any great development of deep ridge terminations. This suggests an origin from some type much more primitive in nature, as discussed in following paragraphs.

In the Walker Museum collections (No. 2204) are a number of incomplete *Sagenodus* dental plates from the horizon of the Coleman Junction limestone in Throckmorton County, Texas; this is in the Putnam formation, at the very top of the Cisco. The formation has been regarded by some as uppermost Pennsylvanian, by others as the base of the Permian; it is certainly much lower in the section (by about 500 feet) than the Wichita deposits from which most of the previously described specimens have come. One lower plate from this horizon pertains to *S. dialophus*.

It has not been possible to fit these plates (Fig. 5*b*, 5*c*, 5*e*) into any one of the previously described Texas species. The palatal plate is broad (in contrast with *S. porrectus*), with a very sharp angulation of the inner margin. The only plate (much worn) with the posterior margin preserved shows 8 ridges plus a small posterior "heel." The first ridge is not complete in any specimen; its proximal portion is low and much worn as in *S. porrectus*. The anterior ridges preserved are much swollen distally; the most distal tubercles are directed sharply outward (Fig. 3*d*). Comparatively unworn specimens show that the tuberculations, although for the most part not very deeply separated, have extended well proximally along the ridges. The only lower plate preserved is imperfect; it is rather broader than that of *S. porrectus*, and with both the ridges and the valleys between curving strongly downwards. This form differs from *S. serratus* (as here interpreted) mainly in the swollen tips of the palatal ridges and the lesser degree of tuberculation, and may have been derived from that species. It may be known as *Sagenodus ciscoensis* sp. nov.

LATE PALEOZOIC CERATODONTS

The genus *Ceratodus* is generally stated not to antedate the Triassic. Though it is perhaps theoretically possible to derive a ceratodont type of tooth plate from that of *Sagenodus*, there is little

evidence of "drift" in such a direction in the members of the last genus. Further, plates suggesting the ceratodont type are found occasionally in late Paleozoic deposits.

A pterygoid tooth plate is shown (No. 2091, Gurley Collection, Walker Museum) embedded in a carbonaceous shale, obtained from the Pennsylvanian (McLeansboro formation) of Carlinville, Illinois. The plate is exceptionally large, measuring 54 mm. in greatest length. The internal margin is strongly angulated. The tooth is very broad and but little indented externally between the ridge termini. No evidence of tuberculations is found on the ridges, and that this appearance is not due to wear is suggested by the fact that the vertical lateral margin is bounded by many bands of enamel, presumably representing consolidated and suppressed denticles. Seven ridges are present, the last a very small one on the "heel." The ridges are moderately well marked, and extend inward nearly to the inner margin; the curvature of the ridges indicates a growth center situated posterior to the angle on the inner margin.

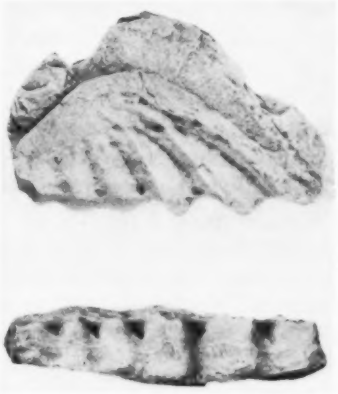

FIG. 6.—*Proceratodus carlinvillensis*, type. ×3/4.

This type of tooth is quite distinct from that found in the common Pennsylvanian genera. The writers term it *Proceratodus carlinvillensis*, as the type of a new genus and species. This genus is established to include forms seemingly ancestral to *Ceratodus*, but differing from that genus in the more pronounced development of the tooth ridges on the dental plates. As specific characters, may be suggested the ridge count, the contours of the ridges, and the angulated inner border of the plate.

The ceratodont type of plate seems to have been an early dipnoan development. "*Ctenodus*" *wagneri* of the Cleveland shale seems to

have been a form of this sort, and may be referred to the present genus as *Proceratodus wagneri*.

From the Permian of Texas, Cope many years ago described *Ceratodus favosus*, based on a fragment of a tooth plate which has been figured by Hussakof. This form generally has been disregarded in discussions of dipnoan evolution. It seems certainly a ceratodont, although the two posterior ridges present exhibit little of the breadth of coronal surface normally seen in this group. Its generic position is uncertain; it provisionally may be referred to the present genus as *Proceratodus favosus*.

It is curious that no second specimen of this type has ever come to light in the last fifty years of Texas collecting. One is tempted to believe that there is some error in the record and that the specimen (clearly, from its color, derived from a red bed) may have been Triassic in origin. But the specimen is recorded as having been collected by W. F. Cummings in Texas on February 4, 1884; it is described in a paper devoted to this collector's finds in the Permian during that season; and Cummings has elsewhere noted that he did not find Triassic beds until some years later. We have thus no reason to doubt the validity of this occurrence.

GNATHORHIZA

This genus was established by Cope for the reception of *Ctenodus pusillus*, a small tooth plate from the Pennsylvanian of Danville, and *G. serrata*, a plate from the Texas Permo-Carboniferous. Hussakof in 1911 demonstrated that *Sagenodus pertenius* of Eastman, from the Wichita group in Wichita County, Texas[10] pertains to the same genus, and he united the three species as *G. pusilla*. The writers believe, however, that it is best to retain the Permian Texas specimens as a distinct species, *G. serrata*. These specimens exhibit the dentition of a small dipnoan, with four ridges above and three below, the longest ridge being the anterior one.[11] There is no crushing power

[10] The types (University of Michigan collection No. 3039) are not from the Cimmaron formation, as Eastman states, nor from Illinois, as Hussakof suggests.

[11] That this orientation of the plates as described by Eastman is correct is suggested by the fact that the lower jaw plate figured by him retains part of the "splenial"; this element appears to show the symphysial position of the bone internal to the long ridge.

whatever. The action is a shearing one, the three lower ridges being interposed externally between the four upper ones; the shear is most highly developed between the long anterior ridges. A derivation of this type of tooth plate from that seen in *Sagenodus* is quite possible.

A similar shearing action is seen in the existing Lepidosirenidae, *Protopterus* of Africa and *Lepidosiren* of South America. A possible connection between *Gnathorhiza* and the lepidosirenids is not mentioned by Cope, Eastman, or Hussakof. It is mentioned only to be rejected as a parallelism by E. Stromer.[12] This negation is based upon three points: (1) the ridges are tuberculated in *Gnathorhiza*, smooth in the lepidosirenids; (2) four upper crests are present in *Gnathorhiza*, only three in the living form; (3) the arrangement of the ridges differs.

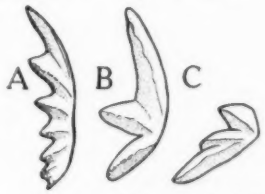

FIG. 7.—Right "splenial" tooth plates of: *A*, *Sagenodus porrectus* (No. 1105, Walker Museum), reversed; *B*, *Gnathorhiza serrata*; *C*, *Lepidosiren*, to show the contrasts in tooth-plate arrangement. Only the ridges of the tooth plates are indicated; the "splenial" and basal portions of the plates not shown. Not to scale.

The first two of these objections are without weight. Obviously the basal tooth plate type from which that of the lepidosirenids has been derived would have been one which had numerous tuberculated ridges, and forms transitional in ridge count and tuberculation must have existed in the ancestors of these living fishes.

The third objection is more serious in nature (Fig. 7). In *Gnathorhiza* it is the presumably most anterior ridge that is the longest; in the lepidosirenids it is the most posterior; in the one case the first ridge is directed forward; in the other, turned sharply outward. This seeming contradiction is not, however, a positive bar to a relationship between these types. In all "normal" Paleozoic lungfish the most anterior ridges are the longest, and are directed forwardly. The most anterior ridge of the lepidosirenids must hence have once been long and forwardly directed, and thus have had the very characters in which that of *Gnathorhiza* seems to differ so radically.[13]

[12] *Festschrift für R. Hertling*, Vol. II (1910), p. 621.

[13] Unless we assume, gratuitously and most improbably, that the whole anterior portion of the tooth plate has been lost.

Long or short, the anterior ridge is the stoutest and functionally seemingly the most important in both types.

The main changes which the tooth plate of a lepidosirenid must have undergone in derivation from that of a dipterid include: (1) reduction in the ridge count, (2) a presumably concurrent reduction of coronal surface and development of shearing function, (3) loss of tuberculation, and (4) shortening and rotation of the anterior ridge. If these changes took place in approximately this sequence *Gnathorhiza* may well have been close to lepidosirenid ancestry. Positive proof is lacking; but we feel that this genus merits provisional inclusion in the Lepidosirenidae.

PEPLORHINA

As noted elsewhere,[14] *Peplorhina* (*Conchiopsis*) *exanthematica* (*anthracina*) Cope, also from the Linton cannel coal, is not an amphibian, as Newberry maintained, but probably a peculiar lungfish of the type of *Conchopoma* of the European Permian. This material merits further study.

SUMMARY

Known American Carboniferous and Permian dipnoans include the following forms and material:

1. From the Mississippian only the tooth plate here described as *Prosagenodus castrensis* gen. et sp. nov.

2. *Ctenodus* is known only from two tooth plates from the Pennsylvanian, *C. plicatus* and *C. cristatus*, from the Joggins, N. S., and Mazon Creek, Illinois, respectively.

3. A majority of known material pertains to *Sagenodus*.

a) *S. serratus*, seemingly the common Pennsylvanian form; the type a tooth plate from the Linton, Ohio, cannel; other material appears to include several plates from Danville, Illinois, to which various specific names have been given by Cope, and a partial skull from Peoria, Illinois.

b) *S. ohioensis*, known only from skull material from Linton.

c) *S. paucicustatus*, represented only by one tooth plate from Danville.

[14] Romer, "The Pennsylvanian Tetrapods of Linton, Ohio," *Bull. Amer. Mus. Nat. Hist.*, Vol. LIX (1930), p. 138.

d) *S. copeanus* of Kansas, described on the basis of a number of tooth plates and isolated cranial elements.

e) Isolated scales which may pertain to this genus have been described from the Pennsylvanian of Mazon Creek and Linton; to these scales a number of specific names of dubious validity have been applied.

f) Four valid species are present in the Texas Permo-Carboniferous "Red Beds"—*S. dialophus, S. periprion, S. porrectus*, and *S. ciscoensis* (sp. nov.).

4. Ancestors of the ceratodonts seem to be represented by *Proceratodus carlinvillensis* gen. et sp. nov., from the Pennsylvanian of Illinois and *Proceratodus? favosus* of the Permian of Texas.

5. *Gnathorhiza pusilla*, from the Pennsylvanian of Danville and *G. serrata* from the Texas Red Beds are known from tooth plates which suggest the lepidosirenid type of specialization.

6. *Peplorhina anthracina* (Pennsylvanian, Linton) is apparently related to the European *Conchopoma*.

STRATIGRAPHY AND PALEONTOLOGY OF A NEW DEVONIAN FORMATION AT BEARTOOTH BUTTE, WYOMING[1]

ERLING DORF
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ABSTRACT

The lenticular outcrop of a fossiliferous channel fill is exposed in the Paleozoic section at Beartooth Butte. It lies unconformably above the Ordovician Bighorn dolomite and below the Devonian Jefferson limestone, and consists chiefly of massive gray limestones and thin red shales. The fossil remains, both faunal and floral, indicate Lower Devonian age. The fauna comprises twenty-nine species of ostracoderms, arthrodires, elasmobranchs, and a dipnoan, in addition to large eurypterid. The flora consists of five species of the most primitive terrestrial plants, the psilophytales. Both paleontologically and stratigraphically the channel deposit is regarded as a new unit in the Paleozoic system of the central Rocky Mountains, so it is named the Beartooth Butte formation. Available evidence shows that it was deposited in relatively quiet water probably in a drowned river valley or estuary.

INTRODUCTION

The widespread transgression of the Middle Devonian seas over the present Yellowstone-Beartooth region, following the Silurian period of erosion, resulted almost everywhere in the disconformable deposition of marine sediments upon the earlier marine sediments of the Ordovician or the Cambrian. At Beartooth Butte, however, there is a channel fill[2] of impure limestone and shale between the marine Ordovician and the typically marine Middle Devonian. The interest in this deposit is as follows: (1) it seems to represent estuarine sediments, which are unusual in the dominantly marine formations of the middle Rocky Mountain Paleozoics; (2) it has yielded a large and rare fish fauna; (3) it has also yielded a small, well-preserved flora which is the first trace of land plants in the Paleozoic of the middle Rocky Mountains; and (4) its fauna and flora indicate that it is a Lower Devonian deposit, thus representing a portion of the Paleozoic system which has not hitherto been reported in this region.

[1] Presented in preliminary form before the Paleontological Society at Boston on December 29, 1932.

[2] The occurrence of this channel fill has been mentioned previously only in *Guidebook 24* of the *XVI International Geological Congress* (1933), Pl. 7 and p. 46, and in the abstract of the writer's paper before the Paleontological Society.

LOCATION OF AREA

Beartooth Butte is situated on the southwestern flank of the Beartooth Mountains, 18.4 miles east of the eastern boundary of Yellowstone National Park. The area lies in the northwest quarter of Park County, Wyoming, 3 miles south of the Montana line, and in Latitude 44° 58′ N., Longitude 109° 37′ W. On the map of the Beartooth national forest, Montana,[3] the butte is in the southwest corner of T. 58 N., R. 105 W., Wyoming, exactly 25 miles southwest of Red Lodge and 16 miles east-southeast of Cooke, Montana. This area is included in the Crandall quadrangle of the *Absaroka Folio, No. 52;* though in this the butte is incorrectly mapped as consisting exclusively of Cambrian strata. Until recently access to Beartooth Butte has been only by horse or on foot. The new Red Lodge–Cooke City road, however, makes it possible to reach Beartooth Lake, lying just southeast of the butte, by automobile.

FIELD WORK

Beartooth Butte was first visited by the writer, accompanied by F. Foote and G. K. Bell, during the summer of 1930, in connection with the Princeton research project, Red Lodge, Montana. A study of the red channel fill exposed in the eastern cliff face of the butte was not made during this short reconnaissance trip. During the summer of 1931 a larger group, consisting of Professors W. H. Bucher, R. T. Chamberlin, E. L. Perry, Mr. R. F. Miller and the writer made another short trip to the butte to complete the plans for a side trip of the C 2 Excursion of the XVI International Geological Congress. The discovery by Dr. Perry at this time of a fish plate in the talus below the channel fill started a rapid search and resulted in a small collection which has been described by Mr. W. L. Bryant.[4]

On the strength of the collection made by the 1931 party the William Berryman Scott Research Fund for Vertebrate Paleontology, Princeton University, authorized the writer to make a two weeks' collecting trip to the butte during the summer of 1932. In this work the writer was accompanied by Professor and Mrs. W. H.

[3] *U.S. Dept. of Agr., Forest Service* (1925).

[4] "Lower Devonian Fishes of Beartooth Butte, Wyoming," *Proc. Amer. Phil. Soc.*, Vol. LXXI, No. 5 (1932), pp. 225–54.

Bucher, S. K. Fox, and S. A. Dorf. The expedition resulted in a more detailed study of the channel deposit and in the collection of over 1,500 pounds of specimens bearing plant and fish-plate impressions. Mr. Bryant continued his studies of the fauna and the writer undertook a study of the plants. The large series of new fish and plant forms made another two weeks' visit in 1933 desirable, under the joint auspices of the Scott Fund and the Department of Geology, Princeton University. This expedition, consisting of Dr. J. S. Smiser, S. A. Dorf, and the writer, in addition to collecting fossils, made a thorough investigation of the entire section at the butte and its vicinity. The detailed descriptions of the faunal and floral remains collected by all parties have recently been published by Mr. Bryant[5] and the writer.[6] Another visit was made to the butte during the summer of 1934 under a grant from the Scott Fund. Very little new material was found, however, to add to the faunal and floral lists published herewith.

GEOLOGY OF THE BEARTOOTH BUTTE REGION

Beartooth Butte is an outlier of Paleozoic sediments situated on the gently dipping southwestern limb of the Beartooth anticlinal uplift. The more continuous Paleozoic outcrops from which the butte has been isolated by erosion are encountered toward the south and west in the Absaroka Mountains, where they underlie a cover of Tertiary volcanics, and again toward the north and east along the Beartooth mountain front, where they are steeply dipping and in places thrust eastward over the Mesozoic and Tertiary sediments of the Bighorn Basin.[7] Most of the Beartooth Butte area (Fig. 1) is composed of the complex of pre-Cambrian granites, gneisses, and basic intrusions which forms the core of the Beartooth Mountains. The butte itself consists of sediments ranging from the Flathead formation of Middle Cambrian age to the Jefferson formation of the Middle De-

[5] "The Fish Fauna of Beartooth Butte, Wyoming," Part I, *Proc. Amer. Phil. Soc.*, Vol. LXXII, No. 5 (1933), pp. 285–314. Parts II and III, *ibid.*, Vol. LXXIII, No. 3 (1934), pp. 127–67.

[6] "A New Occurrence of the Oldest Known Terrestrial Vegetation, from Beartooth Butte, Wyoming," *Bot. Gaz.*, Vol. XCV, No. 2 (1933), pp. 240–57.

[7] For a good cross section of the Beartooth Range showing the structural relations of Beartooth Butte, see A. Bevan, "Summary of the Geology of the Beartooth Mountains, Montana," *Jour. Geol.*, Vol. XXXI (1923), p. 458, Fig. 10, Sec. C.

vonian. The reddish channel deposit, which is here for the first time referred to as the Beartooth Butte formation (for discussion see p.

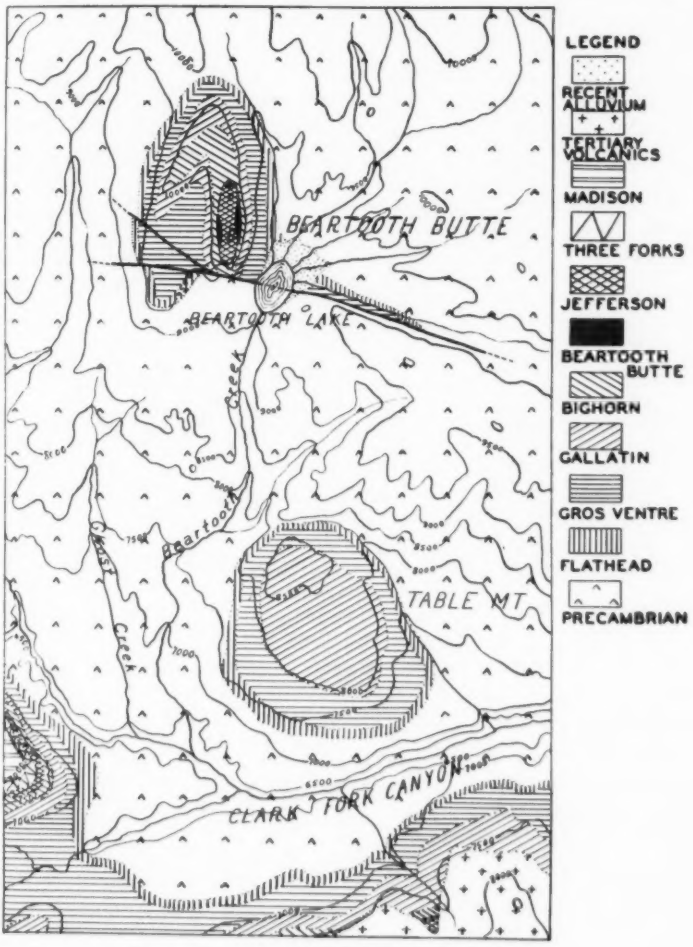

FIG. 1.—Areal geology of the Beartooth Butte area

727), appears on both the eastern and western cliff faces of the Butte between the Upper Ordovician Bighorn dolomite and the Middle

Devonian Jefferson limestone. Table Mountain, south of Beartooth Butte, is an outlier of Cambrian strata only. The exposures of Paleo-

TABLE I

Age	Name	Thickness (in Feet)	Description
Middle Devonian (Erian)*	Jefferson limestone	215+	Chiefly thinly bedded, buffy-brown limestone with fetid odor; sandstones at base.
——Slight disconformity——			
Lower Devonian	Beartooth Butte formation	0–150	Thinly bedded red and buff impure shales, limestone conglomerate and massive gray limestone. Coarse basal conglomerate.
——Marked disconformity——			
Upper Ordovician (Cincinnatian*)	Bighorn dolomite	80	Upper: Massive gray to cream crystalline dolomite.
		100	Middle: Thinly bedded, hard, fine-grained limestone; massive gray mottled dolomite in middle portion. (Leigh formation?)†
		140	Lower: Massive, cliff-forming buff to cream dolomite, mottled with gray. Yellow sandy dolomite at base.
——Slight disconformity——			
Upper Cambrian (including Ozarkian)	Gallatin limestone	348	Upper: Chiefly greenish intraformational conglomerate with buff and brown limestone and greenish gray shale.
		100	Lower: Massive, cliff-forming brown limestone, in places glauconitic and oölitic. (Pilgrim limestone)‡
Middle Cambrian	Gros Ventre formation	353	Upper: Chiefly green and purple micaceous shale and sandstone grading upward into green intraformational conglomerate and shaly brown limestone.
		50	Middle: Thinly bedded brown to drab limestones and greenish papery shales.
		103	Lower: Chiefly green and brown sandy micaceous shales, grading down into green and purple papery shales. (Wolsey shale).‡
	Flathead sandstone	20–50+	Coarse, red and gray banded, arkosic sandstone with basal conglomerate of coarse arkose.
Pre-Cambrian			Chiefly granite gneiss.

* *Guidebook 29, XVI International Geol. Congress* (1933), pls. 2 and 4.

† *E. Blackwelder*, "New Geological Formations in Western Wyoming," *Jour. Wash. Acad. Sci.*, Vol. VIII, No. 13 (1918), pp. 417–26.

‡ C. E. Resser, personal communication.

zoic sediments and Tertiary volcanics at the southern edge of the area are in the Absaroka Mountains, which are separated from the Beartooth Range by the Clark Fork river.

With the exception of the Beartooth Butte formation the stratigraphic sequence at the Butte, Table I, differs only in details of lithology and thickness from the sections exposed in the nearby Cooke City Mining district, as described by Lovering.[8] Throughout most of the Yellowstone-Beartooth region, as outlined by Tomlin-

FIG. 2.—Eastern escarpment of Beartooth Butte; Beartooth Lake in foreground

son,[9] Bevan,[10] and Bucher, Chamberlin and Thom,[11] the Jefferson limestone rests directly, and usually with a well-marked disconformity, on various horizons of the Bighorn dolomite, or even in places on the Gallatin. Almost everywhere the eroded surface on which the first sediments of the Devonian (Jefferson limestone) were laid down

[8] T. S. Lovering, "The New World or Cooke City Mining District, Park County, Montana," *U.S. Geol. Surv. Bull 811–A* (1929), pp. 1–87.

[9] C. W. Tomlinson, "The Middle Paleozoic Stratigraphy of the Central Rocky Mountain Region," *Jour. Geol.*, Vol. XXV (1917), p. 55.

[10] *Op. cit.*, pp. 441–55.

[11] W. H. Bucher, R. T. Chamberlin, and W. T. Thom, "Results of Structural Research Work in Beartooth-Bighorn Region, Montana and Wyoming," *Bull. Amer. Assoc. Petr. Geol.*, Vol. XVII (1933), pp. 680–93.

appears level or with only inappreciable relief. At the Butte, however, the surface on which the first Devonian sediments (Beartooth Butte formation) were deposited has a relief of 150 feet in about half a mile (Figs. 2 and 3). A comparable instance of a relief of 75 feet producing local channels in the top of the Bighorn dolomite is mentioned by Hughes,[12] though in this case the sediments filling in such channels are referred to the basal Jefferson.

In addition to the detailed studies of the channel deposit, lithologic and paleontologic studies have clearly identified the remaining formations at Beartooth Butte with the standard sequence elsewhere in the central Rocky Mountains. A small collection of invertebrates

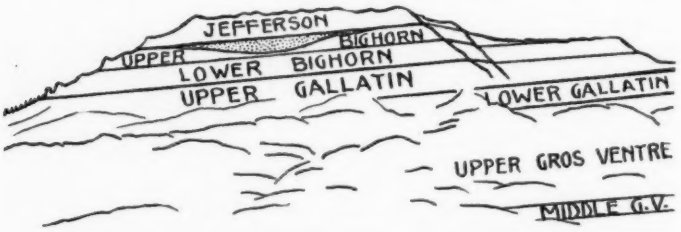

FIG. 3.—Somewhat diagrammatic sketch of same view as Fig. 2, showing formations exposed. Dotted portion is the channel deposit (Beartooth Butte formation).

from the marine Devonian section has been identified by Dr. J. Bridge, of the U.S. National Museum. The Ordovician collections have been referred to the Bighorn dolomite by Dr. W. H. Shideler, of Miami University, and the Cambrian faunas have been identified by Dr. C. E. Resser, of the U.S. National Museum. As will be brought out in a forthcoming paper, considerable reason exists for abandoning the terms "Gros Ventre" and "Gallatin" in the Cambrian system of this and contiguous areas and reverting to formational names originally used by Weed[13] in the Little Belt Mountains of Montana.

[12] R. V. Hughes, "The Geology of the Beartooth Mountain Front in Park County, Wyoming," *Proc. Nat. Acad. Sci.*, Vol. XIX, No. 2 (1933), pp. 239–53.

[13] W. H. Weed, "Little Belt Mountains," *Folio No. 56, U.S. Geol. Surv.* (1899).

DETAILED DESCRIPTION OF THE CHANNEL DEPOSIT

The cross section in the eastern escarpment of Beartooth Butte (figs. 2 and 3), exposes the channel deposit as a slightly asymmetrical lenticular unit with a maximum thickness of 150 feet in the center, from which it thins out rapidly and disappears completely toward the north and south within a horizontal distance of 2,500 feet. A well-marked erosional unconformity is found between the channel fill and the Middle to Upper Bighorn dolomite (Fig. 4).

FIG. 4.—Unconformity between inclined basal conglomerate of the channel fill and the upper portion of the Bighorn dolomite.

The basal conglomerate and limestone beds immediately above this unconformity are inclined to the bedding of the Bighorn as a result of deposition. In the central and upper portions of the deposit, however, the bedding planes flatten out and become essentially parallel to those of the Bighorn below and the Jefferson limestone above. The upper limit of the deposit is well marked by a sharp break in sedimentation and a slight unconformity below the basal conglomerate and sandstone of the Jefferson formation. The color of the channel deposit as a whole is distinctly red. Closer examination, however, shows that much of this is due to surficial staining from the upper beds. Above the basal conglomerate the lower portion of the section (member *B*, Fig. 5) consists of reddish impure

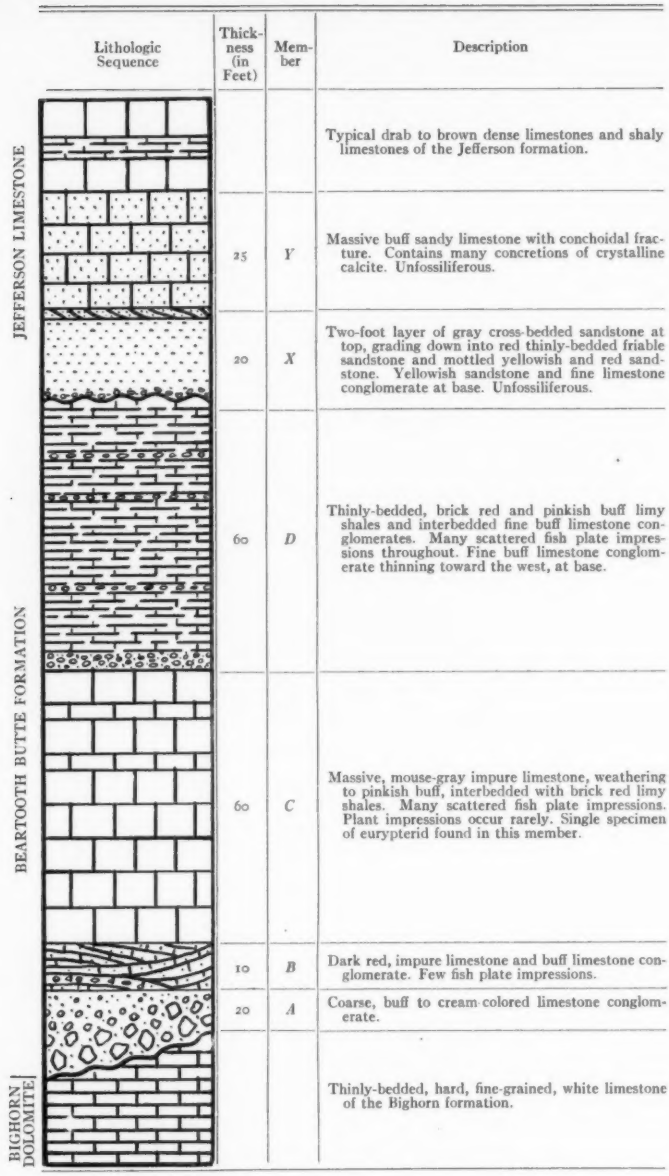
Lithologic Sequence
Thick-ness (in Feet)
Mem-ber
Description
JEFFERSON LIMESTONE
BEARTOOTH BUTTE FORMATION
BIGHORN DOLOMITE
Typical drab to brown dense limestones and shaly limestones of the Jefferson formation.
25
Y
Massive buff sandy limestone with conchoidal fracture. Contains many concretions of crystalline calcite. Unfossiliferous.
20
X
Two-foot layer of gray cross-bedded sandstone at top, grading down into red thinly-bedded friable sandstone and mottled yellowish and red sandstone. Yellowish sandstone and fine limestone conglomerate at base. Unfossiliferous.
60
D
Thinly-bedded, brick red and pinkish buff limy shales and interbedded fine buff limestone conglomerates. Many scattered fish plate impressions throughout. Fine buff limestone conglomerate thinning toward the west, at base.
60
C
Massive, mouse-gray impure limestone, weathering to pinkish buff, interbedded with brick red limy shales. Many scattered fish plate impressions. Plant impressions occur rarely. Single specimen of eurypterid found in this member.
10
B
Dark red, impure limestone and buff limestone conglomerate. Few fish plate impressions.
20
A
Coarse, buff to cream-colored limestone conglomerate.
Thinly-bedded, hard, fine-grained, white limestone of the Bighorn formation.

FIG. 5.—Detailed section of the Channel deposit at its maximum thickness

limestone and buff limestone conglomerate. Member *C* is made up chiefly of mouse gray limestone, weathering to a pinkish buff, which grades upward into brick red and pinkish buff limy shales (member *D*). Intercalated throughout the deposit are pinkish buff to buff limestone conglomerates.

Bedding varies from irregular and lenticular in members *A* and *B* to massive (3–4 feet) and regular in member *C* and finally to very thin ($\frac{1}{2}$–3 inches) and regular in member *D*. Limestone conglomerate beds, one of which shows an appreciable thinning toward the west, i.e., normal to the transverse cross section of the channel, occur at irregular intervals in member *D*. The thinly bedded shales of member *D* split readily along the numerous flat bedding planes, whereas the massive limestone of member *C* possesses only a marked conchoidal fracture, splitting irregularly into pieces usually $\frac{1}{2}$–4 inches in thickness. Not a single instance of cross-bedding was observed above the inclined basal beds. Well-developed mud cracks are common in the thin shaly beds of member *D*. Structurally the channel deposit conforms to the uniform southwesterly dip (average of 5°) of the remaining Paleozoic formations exposed in the eastern cliffs of Beartooth Butte.

In composition the sediments of the channel fill are all distinctly calcareous. Analyses[14] showed that the CO_2 percentage decreases from 34.52 in the massive gray beds of member *C* to 27.49 in the pinkish buff beds of member *D* and finally to 20.71 in the thinly bedded, brick-red beds near the top of member *D*. Inversely, the proportion of sand and clay increases from the bottom of member *C* to the top of member *D* and the texture becomes coarser. A comprehensive report on the sedimentary petrography of the formation is being prepared by Dr. A. Howland, of Northwestern University.

Impressions of fish plates are scattered irregularly throughout the entire thickness, but are abundant only in members *C* and *D*. Plant remains are less numerous and have been found chiefly in member *C*. No trace of typically marine invertebrates has been encountered in the section. The fish plates in member *C* are mostly black or dark gray and are with few exceptions (Fig. 6, illustrations 1 and 8), disarticulated and not in association with impressions of the soft

[14] By Dr. A. H. Phillips, Princeton University.

parts. The majority are uncrushed and usually cut across the fine laminae of the enclosing matrix. In member *D* the fish plates are mostly dark red or black, though some are white, due to the presence of actual bony material. They are usually crushed flat along the closely spaced bedding planes. Distribution along any particular bedding plane is not continuous. The plant remains are commonly black or weathered to brown. The majority of both plant and fish remains were collected from large blocks of talus below the channel deposit on both the east and west sides of the butte. A sufficient amount of material was collected in place, however, to make certain the exact horizons from which the talus blocks had been derived.

FAUNA AND FLORA

The faunal remains are chiefly of ostracoderms and arthrodires, which have been described in detail by Bryant.[15] Twenty-nine species, all of which were new to science, have been distinguished and referred to thirteen genera, eight of which were new. In the following faunal list an asterisk (*) is used to designate the new genera.

Class Ostracodermi
- Order Heterostraci:
  - *Protaspis** *amplus* Bryant
  - *Protaspis* *brevirostris* Bryant
  - *Protaspis* *bucheri* Bryant
  - *Protaspis* *cingulus* Bryant
  - *Protaspis* *constrictus* Bryant
  - *Protaspis* *dorfi* Bryant
  - *Protaspis* *nanus* Bryant
  - *Protaspis* *perlatus* Bryant
  - *Protaspis* *perryi* Bryant
  - *Cyrtaspis** *falcatus* Bryant
  - *Cyrtaspis* *ovatus* Bryant
  - *Cyrtaspis* *papillatus* Bryant
  - *Cyrtaspis* *sculptus* Bryant
  - *Cryptaspis** *ellipticus* Bryant
  - *Cardipeltis* *oblongus* Bryant
  - *sinclairi* Bryant
- Order Osteostraci:
  - *Cephalaspis* *wyomingensis* Bryant

Class Pisces
- Order Arthrodira:
  - *Euryaspis** *brachycephalus* Bryant
  - *Euryaspis* *cristatus* Byrant
  - *Euryaspis* *obscurus* Bryant
  - *Anarthraspis** *chamberlini* Bryant
  - *Anarthraspis* *montanus* Bryant
- Subclass Elasmobranchii:
  - *Machaeracanthus minor* Bryant
  - *Onchus penetrans* Bryant
  - *Onchus peracutus* Bryant
  - *Pinnacanthus** *inequistriatus* Bryant
  - *Helenacanthus** *incurvus* Bryant
  - *Bulbocanthus** *rugosus* Bryant
- Subclass Dipnoi:
  - *Dipterus* sp. (?)

[15] "Lower Devonian Fishes of Beartooth Butte, Wyoming," *op. cit.*; "The Fish Fauna of Beartooth Butte, Wyoming," *op. cit.*, pp. 285–314, and Vol. LXXIII, No. 3 (1934), pp. 127–67.

The Heterostraci are not only the most common forms in number of species but also in relative abundance in the channel deposit. Two new families, the Protaspidae and the Cardipeltidae, were instituted by Bryant. Two of the species of *Protaspis* were found with the fleshy trunk and tail portion in direct association with the carapace (Fig. 6, illustrations 1 and 8). The Osteostraci, though much less abundant, include the first representative of *Cephalaspis* to be found in this country (Fig. 6, illustration 2). Both the genera of arthrodires are unique to the Beartooth Butte formation. The remaining forms, based on spines, are presumably elasmobranchs, and there is a single doubtful dipnoan.

Though all the species of ostracoderms and primitive fishes of the channel fill are new to science several genera were found which previously have been recorded from Lower Devonian deposits in Europe and elsewhere, and most of the species have close parallels abroad. The fauna is more closely related to the Rhenish Lower Devonian of Germany than to any other fauna.[16] Many of the forms from the Downtonian and Lower Devonian of Spitzbergen[17] and the Lower Devonian of Overath,[18] Germany, are closely related to Beartooth Butte forms. In Western North America the small fauna from Blacksmith Fork, Utah,[19] contains several related forms and is, according to Bryant, at least partly of Lower Devonian age.[20]

The collections from the Beartooth Butte formation also include a species of eurypterid, which was submitted for identification to Dr. R. Ruedemann, of the New York State Museum. This has been referred to the genus *Pterygotus* and described in Bryant's report as a new species, *P. princetonii*.

Reproductions of a few of the better preserved ostracoderms and primitive fishes are shown on Figure 6. The reader is referred to the publications by Bryant for complete description and illustrations.

The plant remains are by no means so abundant as the ostracoderms and primitive fishes. Five distinct forms, comprising three

[16] Bryant, Personal communication.

[17] Bryant, "The Fish Fauna of Beartooth Butte, Wyoming," *op. cit.*, p. 287.

[18] *Ibid.*, Vol. LXXIII, no. 3 (1934), pp. 127–67.

[19] E. B. Branson and M. G. Mehl, "Fishes of the Jefferson Formation of Utah," *Jour. Geol.* Vol. XXXIX (1931), p. 509.

[20] "Lower Devonian Fishes of Beartooth Butte, Wyoming," *op. cit.*, pp. 227–30.

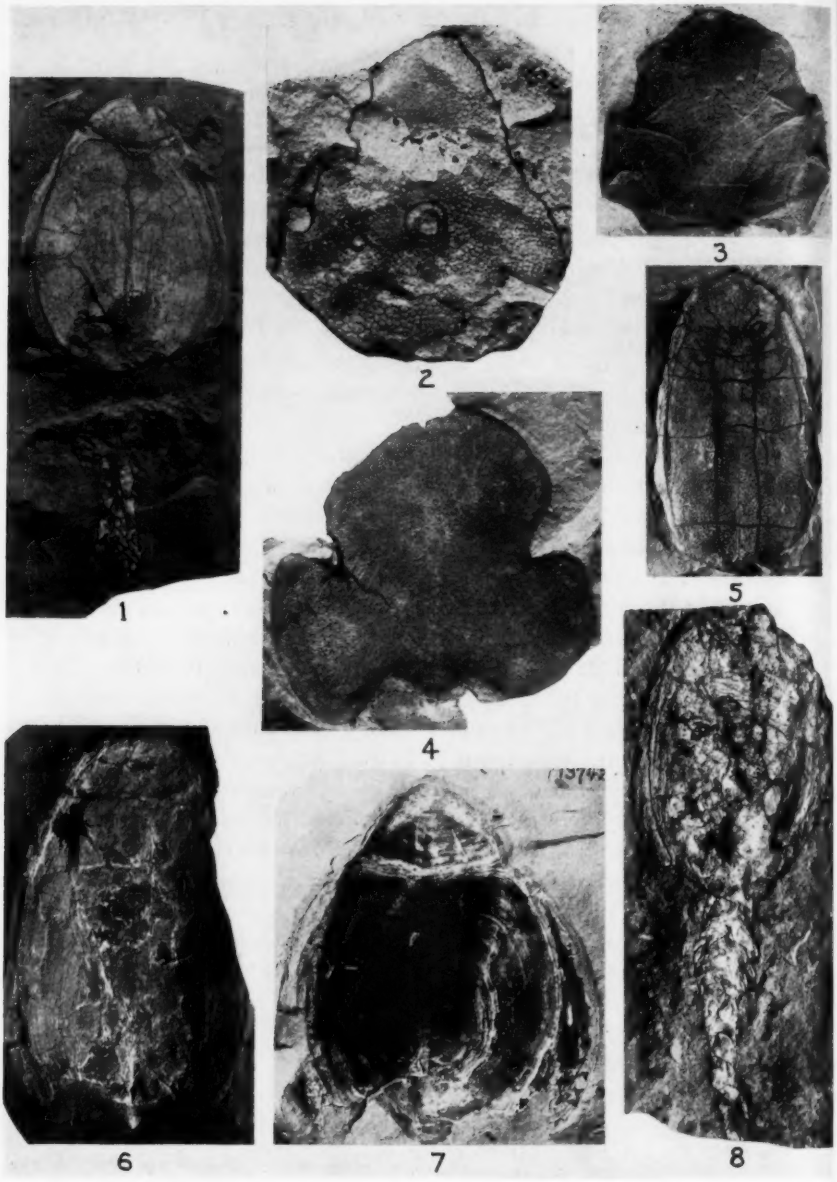

FIG. 6, ILLUSTRATIONS 1–8.—*1. Protaspis dorfi* Bryant, dorsal shield in outer aspect crushed flat and showing trunk with proximal portion of tail. $\times\frac{3}{1}\frac{}{0}$. *2. Cephalaspis wyomingensis* Bryant, fragmentary head shield showing orbits and naso-pituitary openings. $\times\frac{5}{1}\frac{}{0}$. *3. Euryaspis obscurus* Bryant, a cranial shield showing very large eye notches and pointed snout. $\times 1\frac{2}{1}\frac{}{0}$. *4. Cardipeltis sinclairi* Bryant, dorsal shield showing prominent branchial (?) notches. $\times\frac{3}{1}\frac{}{0}$. *5. Cryptaspis ellipticus* Bryant, dorsal shield with outlines of the sensory canal system. $\times\frac{5}{1}\frac{}{0}$. The most primitive of the Heterostraci in the Beartooth Butte fauna. *6. Protaspis bucheri* Bryant, nearly complete dorsal shield. $\times\frac{4}{1}\frac{}{0}$. *7. Cyrtaspis papillatus* Bryant, uncrushed dorsal shield showing annual or seasonal growth rings. $\times\frac{5}{1}\frac{}{0}$. The fish was perhaps 8 years old at death. *8. Protaspis bucheri* Bryant, dorsal and ventral shield crushed together in ventral view, with trunk behind the carapace. $\times\frac{4}{1}\frac{}{0}$. (All photographs on this plate by W. L Bryant.)

new species and one new genus, have been recognized and described by the writer.[21] All of them have been referred to the primitive group, the Psilophytales, which represents the oldest known terrestrial plants. In the following list an asterisk (*) is again used to designate a new genus.

Order Psilophytales:
Psilophyton wyomingense Dorf
(?) *Psilophyton* sp.
*Bucheria** *ovata* Dorf
Hostimella sp.
(?) *Bröggeria strobiliformis* Dorf

This small flora is the first and only known occurrence in Western North America of the so-called "*Psilophyton* flora" of the early Devonian, which has previously been recorded from various localities in Europe, Eastern Canada, and Australia. The association is of essentially the same character as the Lower Devonian flora of Willwerath, Germany, and is comparable in several parallel species to the Campbellton flora of Eastern Canada, the lower Old Red, of Scotland, and the Röragen, of Norway, all of which have likewise been referred to the Lower Devonian.

It is obvious that as a paleontologic as well as a lithologic unit this channel deposit is unlike any previously recorded formation. This fact together with the completeness of the section exposed at Beartooth Butte and the clarity of the stratigraphic relations with overlying and underlying formations seem to justify the proposal to refer to the channel deposit as a new formation, namely the Beartooth Butte formation. Though strictly confined to Beartooth Butte at the present time, it is not unlikely that a closer study of the Ordovician-Devonian contact in the Rocky Mountain region will reveal other channel deposits of similar character and age. On the basis of lithology and stratigraphic relations, but lacking paleontologic evidence, the channel fillings in Park County, Wyoming[22] and in the Shoshone Canyon near Cody, Wyoming[23] clearly can be cor-

[21] "A New Occurrence of the Oldest Known Terrestrial Vegetation, from Beartooth Butte, Wyoming," *op. cit.*, pp. 240–57.

[22] Hughes, "The Geology of the Beartooth Mountain Front in Park County, Wyoming," *op. cit.*, p. 241.

[23] G. D. Johnson, "Geology of the Mountain Uplift Transected by the Shoshone Canyon, Wyoming," Ph.D. dissertation, Johns Hopkins University (1934), p. 27.

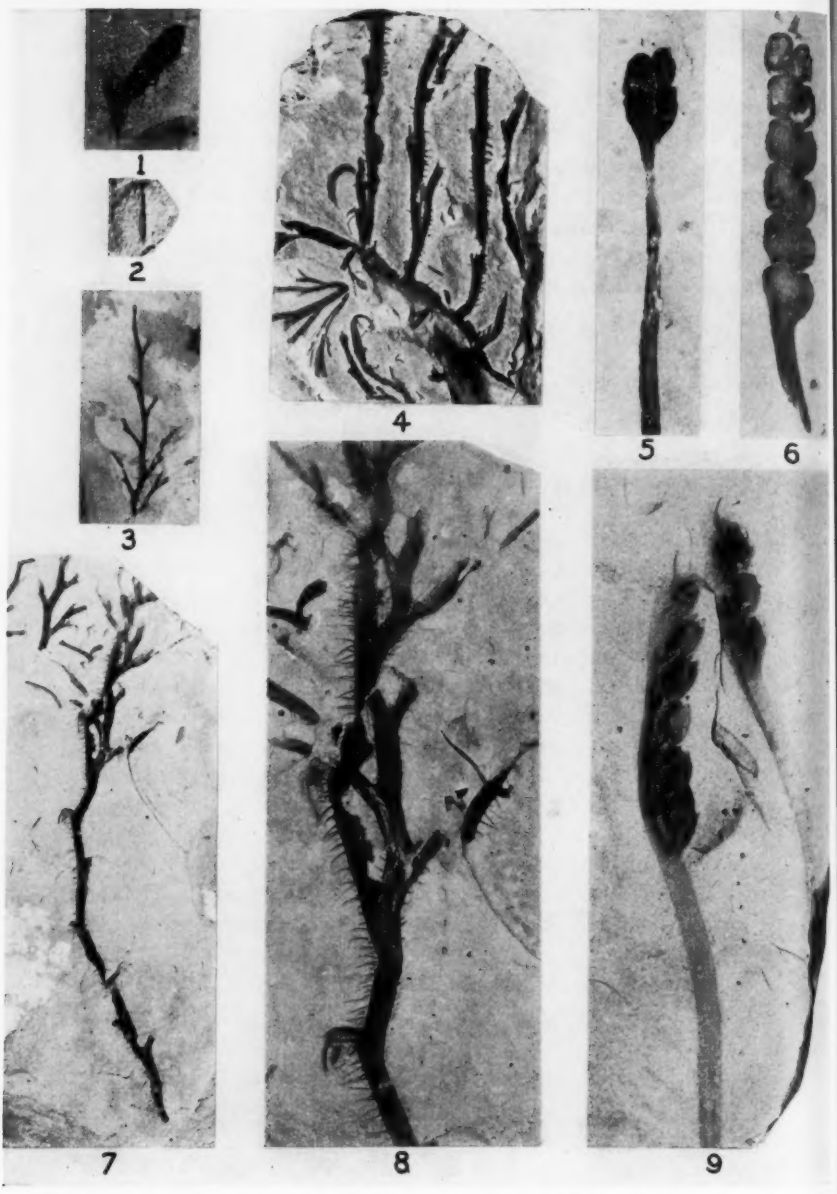

FIG. 7, ILLUSTRATIONS 1–8.—*1*. (?) *Bröggeria strobiliformis* Dorf, showing number of small rounded spore cases (?) in a catkin. ×2. *2*. (?) *Psilophyton* sp., an elongate body, possibly a detached spore case. ×$\frac{2}{3}$. *3*. *Hostimella* sp., showing thin dichotomous branches without spines. ×$\frac{2}{3}$. *4*. *Psilophyton wyomingense* Dorf, showing spiny branches with longitudinal striae and faint scars; oblique stem may possibly be a rhizome. ×$\frac{2}{3}$. *5*. *6*. *9 Bucheria ovata* Dorf, showing terminal clusters of oval spore cases (?) borne on long thin axes without spines. Illustration 5, ×2$\frac{1}{3}$, illustrations 6, 9, ×2. *7*. *8*. *Psilophyton wyomingense* Dorf, showing numerous fine spines on a flattened dichotomous branch. Illustration 7, ×$\frac{1}{3}$, illustration 8, ×1$\frac{1}{2}$.

related with the Beartooth Butte formation. In general characteristics, moreover, the Devonian channel fillings of the Grand Canyon region of Arizona[24] are comparable to those observed in the Beartooth region.

ORIGIN OF THE NEW FORMATION

From the evidence available the writer has come to the conclusion that the sediments of the channel fill, i.e., the Beartooth Butte formation, were deposited in fresh or brackish water under estuarine conditions in a drowned river valley. A discussion of the evidence is presented in the following paragraphs.

The unconformable relationship and the hiatus between the Lower Devonian channel deposit and the Upper Ordovician Bighorn dolomite obviously indicate a period of erosion, which was followed by a period of deposition. The cross section of the depression in which the channel sediments were deposited (Figs. 2 and 3) seems to be that of a river valley in late youth in a region of low relief near the level of baselevel. Above the basal beds (members *A* and *B*), however, the channel sediments do not exhibit any of the characteristic features of fluviatile deposits such as cross-bedding, lenticular or cut and fill bedding, current ripple marks, and heterogeneous distribution of diverse types of sediments (Fig. 5). The general uniformity in texture and the even, parallel bedding, on the other hand, indicate deposition in relatively quiet water. The occasional layers of fine conglomerate show infrequent disturbance of the quiet water by currents. Such general characteristics could have been produced in an estuary along a coastline of subsidence.

Under the hypothesis of an estuarine origin many of the specific features noted in the formation also seem to be adequately explained. The fragments of the coarse basal conglomerates (member *A*) might represent the talus or float which had accumulated in the valley during the period of erosion. The lenticular, heterogeneous beds of impure limestone and conglomerate of member *B* could be stream deposits laid down as a result of the initial slight subsidence of the region. Relatively rapid submergence then followed, drowning the valley to a considerable depth (perhaps 60–70 feet) in fresh to brack-

[24] E. D. McKee, personal communication.

ish water. This submergence seems to have flooded the valley for considerable distance inland for the fine texture, conchoidal fracture, uniform bedding and massiveness of the impure limestones (member *C*) above the basal beds represent a slow, steady accumulation of very fine lime mud, probably in the deeper portion of the estuary at a considerable distance from contributing streams. The coarser, red shales of member *D*, which are thinly and regularly bedded and contain a higher proportion of sand and clay, would indicate either shoaling of the water or closer proximity to the source of the influx of clastics. This may have been the result of the gradual filling in of the basin with or without slight lowering of sea level. Shallow water with frequent exposure to drying is clearly shown by the numerous mud cracks in the shales of member *D*. The occasional layers of fine, water-worn limestone conglomerates in this member would imply infrequent disturbances of the quiet water of the estuary by strong currents from the land, perhaps as a consequence of storms or sporadic, heavy rains. One such current flowing from east to west is indicated by the rapid thinning in this direction of the basal limestone conglomerate of member *D*. This would imply that the mouth of the estuary and the open sea lay to the west of the site of the present Beartooth Butte, which is consistent with the eastward or northeastward advance of the Devonian seas into the central Rocky Mountain region.[25]

Complete submergence of the area, following the deposition of the channel sediments, is indicated by the gradation of the coarse sandy basal beds of the Jefferson limestone upward into typical marine limestones. It is possible, however, that a slight emergent period, represented by the disconformity above the formation, may have preceded this submergence. Another alternative might be that the disconformity was produced by wave action during the gradual, continuous submergence of the land area.

The presence of terrestrial plants in the formation is consistent with the outlined hypothesis of estuarine origin, particularly in view

[25] E. M. Kindle, "The Fauna and Stratigraphy of the Jefferson Limestone in the Northern Rocky Mountain Region," *Bull. Amer. Paleon.*, Vol. IV, No. 20 (1908), pp. 7, 21; C. W. Tomlinson, "The Middle Paleozoic Stratigraphy of the Central Rocky Mountain Region," *Jour. Geol.*, Vol. XXV (1917), p. 55.

of the remarkable preservation of delicate spines and other fragile portions which could not easily have withstood the wave or current action of an exposed sea coast.

The faunal remains, unfortunately, cannot be used to add to such corroborative evidence: The ostracoderms and arthrodires, as well as the eurypterid, though generally considered of fresh or brackish water habitat, lately have been regarded as possibly marine.[26] In the case of the Beartooth fauna, however, the absence of typical marine invertebrates added to the stratigraphic and paleobotanical evidence seems wholly in accord with the hypothesis of fresh to brackish estuarine conditions of deposition.

ACKNOWLEDGMENTS.—The writer wishes gratefully to acknowledge the cooperation of his associates in the field and to express appreciation for the financial aid obtained from the William Berryman Scott Fund and the Department of Geology of Princeton University which made the work possible. In addition the writer thanks Dr. J. Bridge, Dr. W. H. Shideler, and Dr. C. E. Resser for identification of invertebrate collections, and especially Mr. W. L. Bryant for his admirable work on the fish fauna. For helpful criticism of his manuscript the writer is indebted to Professors W. J. Sinclair, P. MacClintock, and W. T. Thom of Princeton University.

[26] Bryant, personal communication.

THE PHYSIOGRAPHY AND GLACIAL GEOLOGY OF THE VALLEY REGION, PARK COUNTY, WYOMING

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ABSTRACT

This article presents: (1) A brief description of the rocks together with the early geologic history of this region; (2) a consideration of the two plateau levels which may represent old erosion surfaces; (3) a discussion of the valley forms and their relation to the glacial history; (4) two hypotheses to explain the depth of erosion by glacial agencies and the amount of postglacial stream erosion. The first hypothesis postulates a small amount of ice erosion and a large amount (500± ft.) of postglacial stream erosion in the lower South Fork Valley together with narrow gorge cutting (600± ft.) in the tributary streams. The second hypothesis, which is favored, requires deepening of the lower South Fork Valley to its present depth by glaciation. This overdeepening left the tributaries as hanging valleys and postglacial erosion was responsible for cutting gorges 600± feet deep in the tributaries and also for cutting the box canyon 500± feet deep in the upper South Fork.

INTRODUCTION

Location.—The area described in this article has been designated the Valley region, after the Valley Post Office located near the center of the area (Fig. 1). Valley is well within the rugged Absaroka Mountains and close to the intersection of the 44th parallel and the 109° 30′ meridian. The South Fork of the Shoshone River, subsequently designated the South Fork, divides the area in half. Physiographically it lies entirely within the Middle Rocky Mountain province.[2]

Rocks.—The rocks of the region are mainly horizontally stratified Tertiary volcanics composed of tuffs, breccias, and basaltic lava flows, all of which are cut by intrusions of various shapes and compo-

[1] Part of a dissertation presented to the faculty of Princeton University for the degree of Doctor of Philosophy. The work was done under the general supervision of Professor W. T. Thom, Jr. I am indebted to Professor Paul MacClintock for consultation in the field and to him as well as to Professor N. M. Fenneman and Dr. W. C. Alden for critically reading the manuscript. I also owe much to Dr. Alden for the loan of his unpublished manuscript on adjacent parts of this area. Thanks are expressed to Mr. R. S. Cannon, Jr., for assistance in the field work and to those in the Valley area who aided me in the work, especially Mr. Merrill Snyder and Mr. I. H. Larom.

[2] N. M. Fenneman, *Physiography of the Western United States* (New York: McGraw-Hill), map.

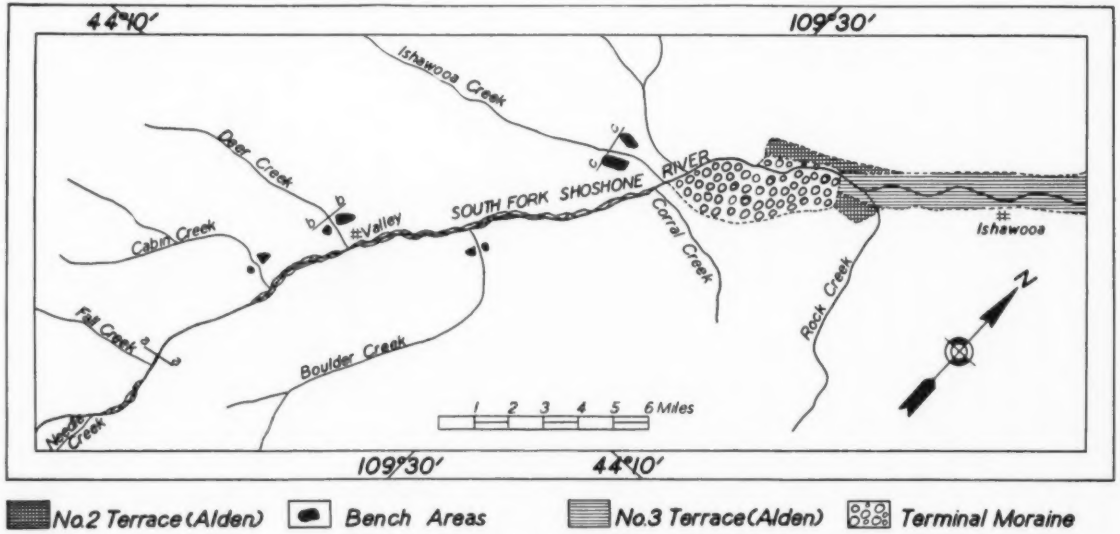

FIG. 1.—Sketch map of the Valley region

sitions. Of the volcanics in this area, the early basic tuffs are the only ones which can definitely be dated. Upon the basis of a tentative determination Professor Dorf, of Princeton University, is of the opinion that the contained flora is of the Fort Union or early Eocene age.[3] All of the volcanic rocks above these tuffs are correlated with those of adjacent regions and assigned to the Miocene.

At the northeast end of the area, where Ishawooa Creek joins the South Fork, a small tongue of sedimentary rocks (Sundance, Jurassic, and Morrison, Cretaceous?), which constitutes the floor of the volcanics, is exposed.

Outline of early geologic history.—1. Deposition of Mesozoic sediments. These tilted and faulted during the Laramide Revolution.

2. Accumulation, in only one very small area, of 250± feet of early acid breccia.

3. Deposition of 400–900 feet of early basic tuffs most of which were water laid.

4. Deformation (small amount of tilting) and erosion which produced a relief of 300± feet.

5. Accumulation of 400–900 feet of early basic breccias. Intrusion of some dikes.

6. Deformation—in some instances producing a dip of 35°. Minor amount of erosion followed.

7. Outpouring of early basalt sheets. Total thickness is 750–900 feet.

8. Accumulation of 2,000–2,500 feet of late basic breccia.

9. Outpouring of late basalt sheets. None occur in this area, but they are present immediately to the north.

10. Regional uplift. Formation of gentle anticline (beds dip 3°–5°) into which the South Fork has cut a valley. A small amount of faulting and an intrusion of stocks, laccoliths, dikes, and sills accompanied or immediately followed this uplift.

PLATEAU LEVELS

The Valley region lies in a large plateau area deeply dissected by many precipitous valleys and gorges.[4] In this vicinity the plateau

[3] Erling Dorf, forthcoming paper.

[4] The reader is referred to Ishawooa quadrangle, Wyo.; U.S. Geol. Surv.

uplands show two separate levels: a lower one at 10,000± feet A.T., and a higher one at 11,500± feet A.T.

Lower plateau.—The lower level extends over large areas such as Ishawooa Mesa and Boulder Ridge. A single area of 8 or 10 square miles, showing a gently rolling surface with wide shallow valleys of former old-age streams, is not uncommon. At the edge of the plateau the shallow valleys end abruptly, giving way to the deep valleys of streams that are rapidly working headward.

The possibility that this plateau might be a stripped plain on a hard-rock stratum is abandoned after observing that the surface of the plateau is developed on the loose, non-resistant breccias. It is difficult to see how such a plateau, at an elevation of 10,000± feet, could be produced in a single cycle by streams which started to cut on the upper surface of the volcanics several thousand feet higher and continued without interruption to the floors of the present valleys. If a stripped plain were to be formed, it would be developed on top of the basalt lava flows, 1,000± feet lower. In a region undergoing such rapid downcutting as this one must have undergone, because of high gradient and soft rock, the breccias should not give rise to wide, extensive flat areas as this, but should rather be deeply dissected to present grade. Nor are there any hard layers in this breccia that would be stripped to develop a plateau at this level. Because of the accordance of the plateau summits, the low relief of the surface of the plateau, the old-age stream aspect, and the stratigraphic location of the plateau, it seems probable that this plateau is a remnant of an older erosion surface subsequently uplifted and deeply dissected.

Higher plateau.—Areas of the higher plateau are much less extensive than areas of the lower one. Where glacial and stream erosion have been particularly vigorous, the flat surface of the higher plateau has been obliterated and now only the roughly accordant peaks suggest its former existence. The theory, however, that there was an erosion surface at this level or perhaps a higher level, cannot be discarded, for two distinct erosion surfaces are recognized in many of the ranges of the Rocky Mountain region. Although sufficient evidence does not exist here to support any contention that the upper plateau remnants represent an old erosional plain, as do those of the

lower plateau, still it cannot be stated definitely that a higher erosion surface did not exist. It may have existed in earlier geologic time and then been subsequently destroyed at the time the surface, now represented by the lower plateau, was being made.

Looking east from Boulder Ridge, one will see that the rise to the upper plateau is a steep escarpment composed of the same upper breccias as the lower plateau. This escarpment was estimated to be 1,000–1,500 feet high, and although not examined in detail, none of the upper lavas were observed on it. During erosion of the surrounding country, this was, no doubt, present as a retreating escarpment, standing above the surrounding plain (now the lower plateau). A capping of lava, subsequently removed, may be one explanation for the persistence of this scarp at the time of this erosion.

Other remnants of the upper plateau, the higher peaks, such as Ishawooa Cone, Thorofare Buttes, and numerous divides (such as those between Pass and Open creeks and Hidden and Thorofare creeks) are capped with remnants of the late basalt sheets. It is probable that most of the peaks of the upper plateau were, at one time, capped with this same basalt. The erosion cycle was not long enough to permit peneplanation and these peaks, capped by hard rock, were monadnocks or residual ridges standing above the erosion surface (lower plateau).

Correlation of the present plateau levels.—In the Beartooth Mountains Bevan[5] recognized two peneplains: an older one, the Summit peneplain at an elevation of 12,000 feet, and a Subsummit peneplain some 2,000 feet lower. In a description of the latter[6] he mentions the presence of erosional surfaces (10,000± ft. A.T.) on the breccias of the Crandall area[7] that might be correlated with the Subsummit peneplain. The writer believes that the lower plateau (10,000± ft.) of the Valley region is equivalent to the 10,000-foot level of the Crandall sheet.

In the Valley region the higher plateau remnants do not necessarily represent a summit peneplain, but in any case they represent residual

[5] Arthur Bevan, "Summary of the Geology of the Beartooth Mountains, Montana," *Jour. Geol.*, Vol. XXXI (1923), pp. 441–65.

[6] Arthur Bevan, "Rocky Mountain Peneplains Northeast of Yellowstone National Park," *Jour. Geol.*, Vol. XXXIII (1925), pp. 363–87.

[7] Crandall is the quadrangle adjoining Ishawooa quadrangle on the north.

peaks and ridges which rose above the surface of the graded plain and may be similar to the higher masses rising to 12,000 feet or more in the Beartooth region.

VALLEY FORMS

South Fork.—This valley, together with its larger tributaries, has been severely glaciated. Between Cabin and Ishawooa creeks the river is braided, flowing on the bottom of a U-shaped valley 1½–2

FIG. 2.—Looking southeast across the valley of the South Fork at Valley. Note the braided character of the stream and the landslide topography between the steep cliffs and the river.

miles wide and 4,000± feet deep (Fig. 2). Above Cabin Creek the valley is less than one-half mile wide and its U-shape is modified by a narrow postglacial box canyon 500± feet deep cut in the base of the U (Figs. 3 and 4). Above Fall Creek the box canyon ends, the valley widens slightly and the South Fork again flows as a braided stream on the floor of the extremely steep U-shaped valley. The river is braided only as far as Needle Creek, for above here the valley narrows and canyons are numerous.

In general, the width of the South Fork Valley varies with the resistance of the rocks. The widest part of the valley is underlain by

soft volcanic rocks, but upstream (above Cabin Creek), where the valley suddenly narrows, the volcanics give way to a resistant quartz-diorite stock which has retarded both glacial and stream erosion. The slight widening of the valley above Fall Creek is due to the recurrence of the weak volcanics.

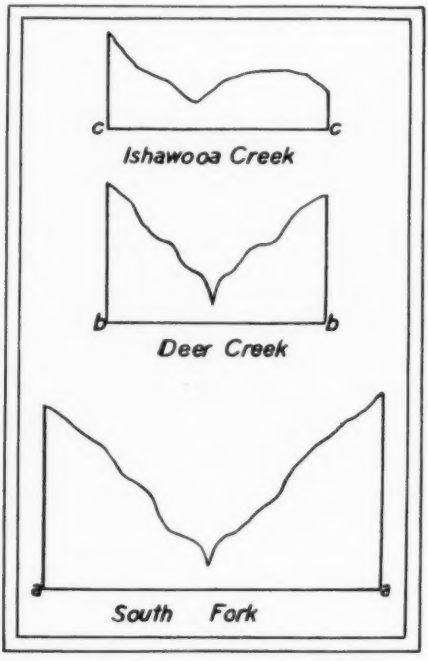

FIG. 3.—Cross sections of valleys showing the postglacial gorges. The letters *a–a*, etc., refer to the locations on the map (Fig. 1).

Between Ishawooa and Cabin creeks small benches, all approximately 500 feet above the river, are located on the sides of the main valley and adjacent to the larger tributary streams (Fig. 1). All of these benches are veneered with unassorted glacial boulders which represent a lateral moraine.

In the South Fork Valley, immediately below Ishawooa Creek, a belt of terminal moraine 5 miles wide is found.

Tributary valleys.—In the vicinity of Valley the tributary valleys show a U-shaped cross section down to about 600 feet above the South Fork. This is interpreted as the limit of glacial downcutting. Below this level the tributaries have cut deep, precipitous gorges to

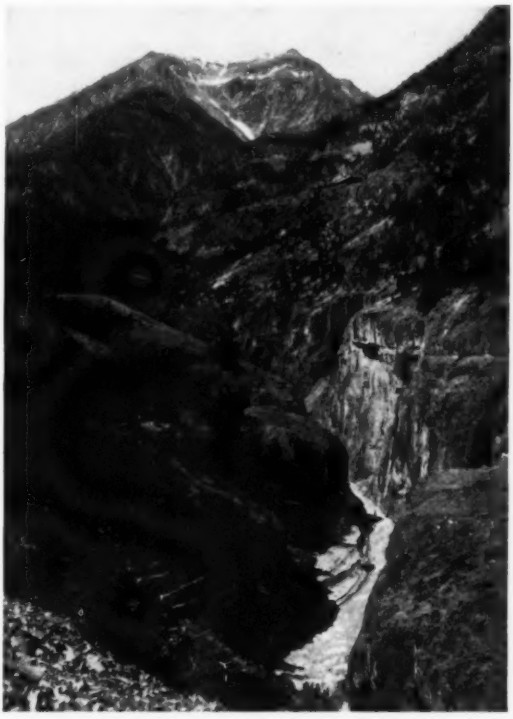

FIG. 4.—Looking upstream through the box-canyon of the South Fork. Compare this canyon of the South Fork with the valley of the same stream shown in Fig. 2. (Photo by Edward Sampson.)

the grade of the main valley (Fig. 3). In Deer Creek the postglacial canyon progressively shallows upstream, finally merging with the floor of the glacial valley, 3 miles above its mouth. Similar features are observed in Cabin and Boulder creeks. Ishawooa Creek, however, has cut a narrow valley, rather than a precipitous gorge, in the

bottom of its old U-shaped valley. The development of a valley here rather than a gorge, is due to the greater size of Ishawooa Creek and the absence of any hard intrusive rock such as is found in the canyon of the South Fork.

Terraces northeast of the area.—Just beyond the limits of the area studied and northeast of the terminal moraine the terraces of the South Fork have been briefly described by Alden.[8] According to him the No. 2 terrace, consisting of an upper No. 2 and lower No. 2, is particularly well developed and is 250–300 feet above the present level of the South Fork. The No. 3 terrace is also well defined and is 100± feet above the South Fork. Southwest of Rock Creek the terminal moraine covers both the No. 2 and the No. 3 terraces.

During the summer of 1933, the writer, in the company of Professor Paul MacClintock, made a study of the terminal moraine (Wisconsin) and the terraces described by Alden in the immediate vicinity of this moraine hoping that such a study would throw some light on the interpretation of the history of the upper South Fork. The following interpretation of the sequence of events, essentially the same as that of Alden, was reached.

1. Formation of upper No. 2 terrace
2. Formation of lower No. 2 terrace (No. 2′)
3. Deposition of alluvial fans on No. 2′
4. Formation of No. 3 terrace
5. Cutting 30′ to form lower No. 3 terrace (No. 3′)
6. Deposition of moraine on No. 2, No. 2′ and No. 3 terraces

Beyond the terminal moraine No. 3 terrace has not been glaciated. This unglaciated portion of No. 3 terrace is approximately 250 feet wide and 150 feet above the South Fork. In Figure 5 *A* is clearly not an erosional scarp, but a rise produced by the deposition of terminal moraine on No. 3 terrace, while *B* is definitely a meander scar produced at the time No. 3′ terrace was being formed. In Figure 6 the old meander scar, produced when the river cut below No. 3, is quite evident.

The writer believes that the No. 3 terrace is to be correlated with

[8] W. C. Alden, "Physiography and Glacial Geology of Eastern Montana and Adjacent Areas," *U.S. Geol. Surv. Prof. Paper 174* (1932); unpublished preliminary manuscript describing the terraces and benches in the Bighorn Basin and on the South Fork of the Shoshone River.

the benches observed in the vicinity of Valley. If the slope of the No. 3 terrace is continued upstream, it will intersect the valley side approximately at the elevation of the benches.

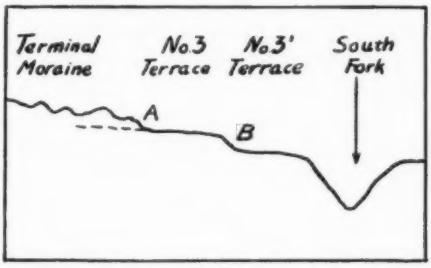

FIG. 5.—Diagrammatic sketch showing relation of the terminal moraine to the terraces.

FIG. 6.—Looking northwest across the South Fork below the terminal moraine. Terraces No. 3′ and No. 3 are shown in the foreground and No. 2, covered by an alluvial fan, in the background fronting the mountain slopes. The narrow wall at the right is a basalt dike. (Photo by Paul MacClintock.)

PROBLEMS OF GLACIATION

In an attempt to explain the depth of both glacial and postglacial erosion in the valleys, two alternative hypotheses are presented for consideration.

1. After the withdrawal of the last ice from this region the floor of the lower South Fork Valley was possibly at the level of the benches (Fig. 1) (500± ft. higher than the present valley floor) with the tributaries in adjustment. The cutting of all the valleys to their present depth was, therefore, accomplished by postglacial stream erosion.

2. Glaciation deepened the lower South Fork Valley to its present depth and left the benches as isolated remnants of an older valley floor; but the action of the ice in the tributary valleys was not so vigorous and these were left as hanging valleys, their floors being 600± feet higher than the floor of the South Fork Valley.

If the first hypothesis is correct, then in order to inaugurate a cycle of downcutting to bring the valleys to their present level (500± ft. below the benches), it is necessary to assume rejuvenation of the streams following the withdrawal of the last ice sheet. Such postulated rejuvenation would necessarily have been of the normal type affecting the entire region. No evidence is found of a northeast tilting which would have been necessary to cause rejuvenation of only the South Fork leaving hanging tributary valleys of the type described by Matthes.[9] As there was no such tilting, it seems unwarranted to assume that the broad main valley was lowered 500± feet by stream erosion following glaciation, while the tributaries cut only narrow gorges in the floors of the U-valleys. The only point which might harmonize with this hypothesis is the close agreement of the bench levels with the floor of the terminal moraine, but this evidence alone does not furnish adequate support to the hypothesis.

According to the second hypothesis the benches may represent remnants of either an older river valley, formed by normal downcutting of the South Fork, or the floor of an old glacial valley, as suggested in the first hypothesis. Regardless of the origin of this old valley, it is postulated that it was deepened by the last glaciation to its present level in the vicinity of Valley. Above Cabin Creek, however, at the present box canyon of the South Fork, glaciation was not so vigorous because of the presence of more resistant rock and here the floor remained 500± feet above the present river level. This

[9] F. E. Matthes, "Geologic History of Yosemite Valley," *U.S. Geol. Surv., Prof. Paper 160* (1930), p. 34.

canyon has, therefore, been produced by stream erosion since the withdrawal of the ice. The tributary valleys, occupied by smaller glaciers, were not cut so deep as the main valley, and when the ice withdrew they remained as hanging valleys, into which postglacial erosion has cut the present gorges. Such a hypothesis would not require as great amount of postglacial erosion as does the first one. In this case postglacial erosion would be responsible for only 500± feet

FIG. 7.—Deposition of an alluvial fan at the mouth of Yellow Creek has dammed the upper South Fork.

of downcutting by the South Fork in a narrow canyon and about 600 feet of downcutting by the tributary streams in smaller gorges.

But we have been considering only the Wisconsin age of glaciation.[10] It has been suggested that the greater part of the ice erosion might have taken place in an earlier glacial stage; that most of the gorges were cut in the following interglacial stage; and that during Wisconsin time glaciation amounted to merely a filling of the valleys with Wisconsin ice with no appreciable amount of ice erosion.

Adequate evidence that the canyon and gorge cutting has been

[10] W. C. Alden, *op. cit.*, Plate I (Western Half). Alden maps the terminal moraine as Wisconsin.

accomplished since Wisconsin time should be found in the following facts and field observations.

1. The canyon in the main valley of the South Fork was cut through a hard quartz-diorite by the master stream of the region, but

FIG. 8.—Natural bridge, Deer Creek, looking upstream (West). (Photo by Pau MacClintock.)

the streams of the tributary valleys cut only through well-jointed volcanic tuffs and breccias which erode very easily. Furthermore, the present rate of deposition would imply rapid erosion in this region. During one cloudburst in August, 1930, Deer Creek deposited alluvium 9 feet deep at its mouth and in the same season Yellow Creek, a tributary of the upper South Fork, deposited an alluvial fan

of such magnitude at its mouth that it temporarily dammed the river (Fig. 7).

2. In the deep gorge of Deer Creek the stream flows through a most picturesque and significant natural bridge (Fig. 8) formed by undercutting during the growth of an entrenched meander. The bridge, composed entirely of soft tuff, is about 25 feet high, from the stream level to the base of the span, 15 feet wide immediately under the span, and 25 feet wide at the base of the span. If this bridge were developed prior to the last glaciation, the writer is at a loss to explain

FIG. 9.—Landslide topography. East side of the South Fork opposite Valley. (Photo by J. B. Lucke.)

how it was able to remain through the last ice stage. If the valley were filled with ice there certainly would have been sufficient movement of the ice to remove the span. Nor could the sheer cliffs, in many places undercut 15 to 25 feet, present in Deer Creek and other tributaries, persist through an ice age. In none of the canyons of the tributary streams, nor in the box canyon of the South Fork, was the writer able to find any evidence indicating that these canyons had been filled with ice.

3. Opposite Valley, on the southeast side of the river, there is a belt of landslide hills approximately 4 miles long and 1 mile wide. The hills show sharp ridges aligned northeast-southwest parallel to Boulder Ridge (Figs. 2 and 9). This landsliding probably occurred soon

after the valley was brought to its present level by glacial erosion. If the deepening of the South Fork occurred at an earlier period of glaciation and Wisconsin glaciation later affected the region, it is to be supposed that the sharp crests of the landslide hills would be less sharp than they are now.

4. Several additional facts indicate that the lower main valley of the South Fork was brought to its present depth by Wisconsin glaciation. The benches in this region are correlated with Alden's No. 3 terrace on which the Wisconsin terminal moraine rests. It is evident, therefore, that in the Valley region glaciation has removed most of the No. 3 level, but to the northeast it was not able to do so and there deposited the terminal moraine on the terraces. Furthermore, the changing of the gradient of the South Fork so that it is no longer cutting, but is rather filling, can best be explained by overdeepening through the action of glacial ice.

The foregoing arguments favor the second hypothesis, namely, that the lower South Fork Valley, between Cabin and Ishawooa creeks, was deepened to its present level by Wisconsin ice. This valley, above Cabin Creek, and all the tributary valleys were brought to their present depth, 500–600 feet below the glacial valley floor, in post-Wisconsin time.

FOOTPRINTS FROM THE PERMIAN OF WEST VIRGINIA

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Columbia University
AND
HERBERT ALEXANDER
Marietta College

ABSTRACT

The discovery of fossil footprints in the Permian Dunkard formation of West Virginia is offered as announcement of a new locality where two or more new species are apparently represented. The character of the material collected does not permit complete description of the species.

A new locality for Permian fossil footprints was found by the writers in the spring of 1930, at Sherman, West Virginia, a hamlet on the east side of the Ohio River, about 3 miles north of Ravenswood. The specimens occur on loose blocks in the spall pile of an abandoned grindstone quarry, on the south side of Little Sandy Creek about 1 mile east of the Ohio River. The quarry is in a sandstone member of the Dunkard formation, tentatively correlated with the Lower Marietta sandstone.

Two species, and possibly a third, are represented; one by a single track, the others by numerous tracks scattered over a dozen or more of the large quarry blocks. The single specimen of one species, and a block showing fifteen tracks of the other, or others, have been deposited in the museum of Marietta College.

The single specimen of one species is an obverse cast (Fig. 1 *A*), flat topped and about 2 mm. high. Four digits are clearly shown, and there is possibly a fifth less clearly defined. The length of track, measured along any of the well-defined digits, is about 7 cm., and the greatest span of these digits is 12 cm. The width at heel is 9 cm. The four distinct digits are each 2.5 cm. long and 2 cm. wide at the base.

Figure 1 *B* represents a slab of sandstone 3 by $3\frac{1}{2}$ feet, with fifteen footprints. These footprints apparently have five digits, although never more than four can be definitely recognized in any one track.

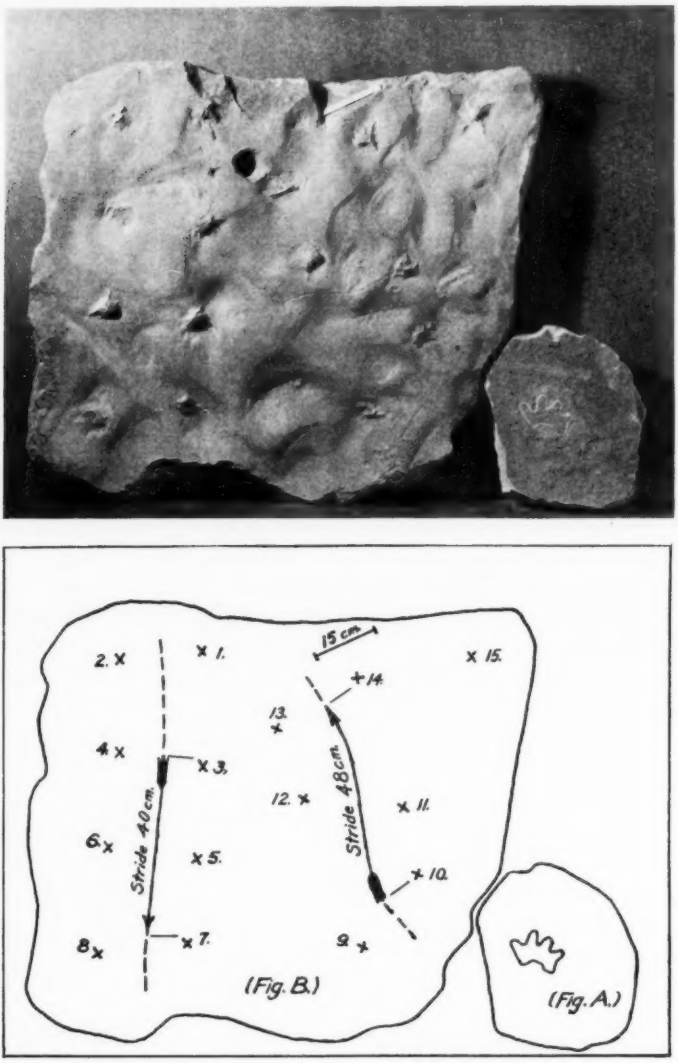

FIG. 1.—Photograph and interpretive diagram of new fossil footprints from Sherman, W. Va.

The tracks vary in length from 6 to 7 cm., and in width from 7 to 8 cm.; with the exception of a few doubtful cases of poor preservation, all are definitely wider than long. The digits reach a length of 4 cm. and are about 1 cm. wide at the base. Several tracks show what may be indistinct claw marks.

The tracks are obscured considerably by tightly adhering matrix from the overlying bed, thus making it difficult to interpret their arrangement. The sketch accompanying the photograph shows what the authors consider the most reasonable explanation. Tracks numbered 9–14 appear to indicate a longer stride than those numbered 1–8. This may indicate different species, since the arrangement of tracks is quite different, but the individual tracks are not sufficiently clear to justify positive conclusions. Or the two trackways may have been made by the same animal, or two individuals of the same species but perhaps different size, for tracks 1–8 indicate a nearly straight path, though 9–14 may have been made by an animal turning somewhat from side to side as it advanced, or possibly only traveling more rapidly. The stride indicated for these two sets of tracks is 40 cm. for those numbered 1–8, and about 48 cm. for those numbered 9–14. Number 15 seems the only representative of another set, which, so far as the material goes, seems more like those numbered 1–8.

No tail marks were seen on any of the slabs, and none of the other slabs carry enough tracks to give definite indication of arrangement along the trackway. No similar sequence or spacing was seen on these other slabs, but the arrangement suggested a narrower trackway with individual tracks alternating on opposite sides of a median line, and a stride of at least 60 cm. It is not evident whether this indicates that the sequence as figured is abnormal or accidental, or whether the other slabs carry only occasional tracks which happened to be more strongly impressed or for some reason better preserved than others.

STUDIES FOR STUDENTS

SOME NOTES ON THE NOMENCLATURE OF FAULTS[1]

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ABSTRACT

The terms "throw" and "heave" have three independent meanings in fault terminology. The usage of these two terms as suggested by the Committee on Fault Nomenclature of the Geological Society of America has not been universally accepted, nor is it likely to become standard. The writer proposes that the terms *throw* and *heave* be abandoned, and that descriptive language be used in fault discussions.

Probably no portion of geologic literature has a more confused terminology than that dealing with faults. Ransome,[3] as long ago as 1906, called attention to the pressing need for a re-definition of terms, whereupon Tolman[4] and Reid[5] undertook a revision of the nomenclature, the one by proposing a new terminology, and the other by detailing the geometry of faulted structures. The Council of the Geological Society of America, largely as a result of Ransome's suggestion, appointed a committee on fault nomenclature at the Baltimore meeting in 1908. This was done in the hope that, by codifying existing terms, redefining some, and adding others, a terminology might be produced which would become standard with English-speaking geologists. In December, 1912, the committee made its final report, presenting a complete nomenclature together with suggestions for teaching.

That much progress has resulted from the work of this committee

[1] Delivered in substance before the West Virginia Academy of Science, April, 1932, under the title, "Some Confused Terms in Fault Nomenclature."

[2] Present address, Princeton, West Virginia.

[3] F. L. Ransome, "The Direction of Movement and the Nomenclature of Faults," *Econ. Geol.*, Vol. I (1906), pp. 777–87.

[4] C. F. Tolman, Jr., "How Should Faults Be Named and Classified?" *Econ. Geol.*, Vol. II (1907), pp. 506–11.

[5] H. F. Reid, "Geometry of Faults," *Bull. Geol. Soc. Amer.*, Vol. XX (1910), pp. 171–96.

is evident from an examination of the textbooks now in common use in this country, but it is equally clear that a few of the terms have not met with general approval, or have been overlooked in later editions of older texts. This is natural enough, as many of the terms not favored by the committee were deeply entrenched in the literature, and many authors were using a nomenclature which seemed to them preferable to that proposed by the committee. It is the purpose of the writer to point out the present variation in usage of two of these terms: *throw* and *heave*.

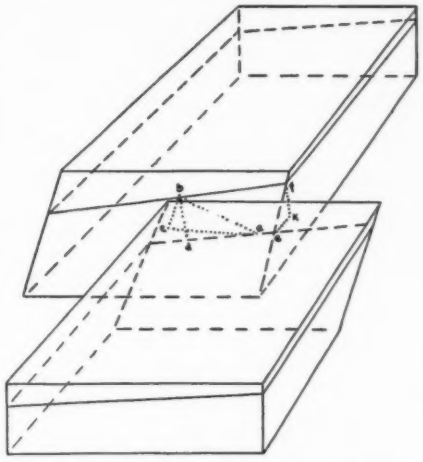

FIG. 1.—Illustrates the terms recommended by the committee. It is important to observe that no name is given to the vertical component of the fault movement, or to the horizontal component normal to the strike.

ab	the net slip
ad	trace slip
ac	strike slip
bd	perpendicular slip
bc	dip slip
cd	no name
fk	throw
ek	heave

(Drafting by Louise Waldruff)

Accepting the original usage of these two terms, which were first introduced in the coal fields of Great Britain, the committee wrote:

The *throw* is the vertical distance between corresponding lines in the two *fracture surfaces* of a disrupted stratum, et cetera, measured in a vertical plane at right angles to the fault strike.

The *heave* is the horizontal distance between corresponding lines in the two fracture surfaces of a disrupted stratum, et cetera, measured at right angles to the fault strike. These distances must be measured between *corresponding* lines—for instance, between the upper edges of the two *fracture surfaces* of the stratum or between their lower edges, but not between the upper edge of one fracture surface and the lower edge of the other.

In Figure 2 [see Fig. 1] the ends of the block are vertical sections at right angles to the fault strike; *fk* is the throw and *ek* is the heave. In Figure 3 [see

Fig. 2] *cg* (*ac*) is the throw and *bg* (*bc*) the heave, if the strikes of the fault and the strata are parallel. . . . . The words "throw" and "heave" have been used in various senses. A. Geikie uses "throw" for the distance . . . . which we have called the vertical separation, and Spurr for the separation along the dip of the fault plane. J. Geikie, Willis, Scott, and Fairchild use "heave" practically as it is defined above. A. Geikie and Spurr make it equivalent to the offset. Jukes-Brown apparently used it for strike slip (de Margerie and Heim, p. 72); so did Ransome, and Scott also uses it in this sense when he refers to "heave faults." The throw has also been called the "vertical throw" and the heave the "horizontal throw," but this usage is not recommended.[6]

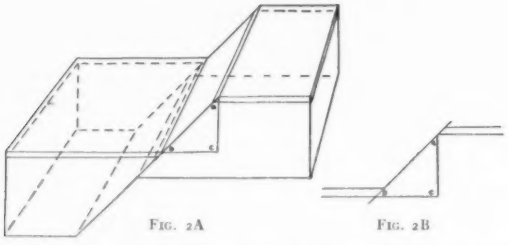

FIG. 2A FIG. 2B

FIG. 2A.—Its most common interpretation in three dimensions
FIG. 2B.—Reproduction of the section most frequently used in textbooks
(Drafting by Louise Waldruff).

The committee plainly stated that its definitions are geometrical and that they deal with relations among the beds, not with fault movements. Others prefer to define fault relations in dynamic terms. This difference in point of view has led to many of the confusing usages in fault terminology and descriptions. It is true that where *dip slip* faults in horizontal strata alone are considered (as must be the case in many, if not most, of the textbooks) the *throw* and the *heave* are respectively the vertical and the horizontal (normal to the strike) components of the fault movement. But such is not the case where the beds are inclined materially from the horizontal, or the fault movement has been oblique (Fig. 3).

In an analysis of textbook usage, the writer has consulted only works which have been published or revised since the report of the committee. No effort has been made to cover all available text-

[6] H. F. Reid, *et al.*, "Report of the Committee on the Nomenclature of Faults," *Bull. Geol. Surv. Amer.*, Vol. XXIV (1913), p. 176.

books, but twenty-nine of the more representative ones, many of them revisions of earlier editions, have been examined. These texts have been divided into three groups, based upon the usage of the two terms under discussion: the first group comprises those following the usage of the committee; the second, those giving the term

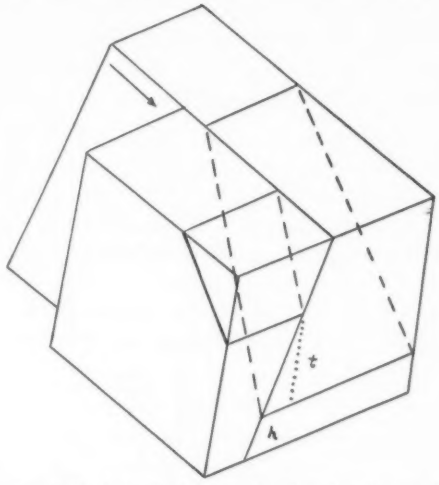

FIG. 3.—A strike-slip fault in tilted strata, showing that *throw* and *heave* as defined by the committee are not necessarily components of the fault movement. (Drafting by Louise Waldruff.)

throw the meaning which the committee reserved for the term *slip;* the third, those using the terms for components of the fault movement.

In the first group are: Brigham and Burt,[7] all editions of Lahee,[8] Scott's 1916 edition,[9] the United States Geological Survey,[10] and both editions of Willis.[11]

[7] A. P. Brigham and F. A. Burt, *Geology*, (Rev. ed.; New York: Appleton, 1921), p. 217.

[8] F. H. Lahee, *Field Geology* (New York: McGraw-Hill, 1916), p. 186; (2d ed.; *ibid.*, 1923), pp. 192–99; (3d ed.; *ibid.*, 1931), p. 217.

[9] W. B. Scott, *An Introduction to Geology* (2d ed.; New York: Macmillan Co., 1916), p. 340.

[10] D. F. Hewett, "Geology and Ore Deposits of the Goodsprings Quadrangle," *U.S. Geol. Surv. Prof. Paper 162* (1931), pp. 42–43.

[11] Bailey Willis, *Geologic Structures* (New York: McGraw-Hill, 1923), p. 108; Bailey and Robin Willis (2d ed.; *ibid.*, 1929), pp. 152–53.

In the second group are: Spurr,[12] who follows closely his first edition[13] in this respect, and the first edition of Leith,[14] which was ready for publication before the report of the committee was presented.

In the third group are nineteen textbooks, as follows: Chalmers,[15] Chamberlin and Salisbury's revised shorter text,[16] which parallels the first edition[17] and the larger treatise,[18] Cleland,[19] Cox, Dake, and Muilenburg,[20] Dake and Brown,[21] Elles,[22] Emmons, Thiel, Stauffer, and Allison,[23] Grabau,[24] Leith's revised edition,[25] Longwell,[26] Miller,[27]

[12] J. E. Spurr, *Geology Applied to Mining* (2d. rev. ed.; New York: McGraw-Hill, 1926), p. 98.

[13] *Ibid.* (New York, Engineering and Mining Jour., 1904), p. 159.

[14] C. K. Leith, *Structural Geology* (New York: H. Holt & Co., 1913), p. 32.

[15] R. E. Chalmers, *Geological Maps* (London: Oxford University Press, 1926), pp. 100–102.

[16] T. C. Chamberlin and R. D. Salisbury, *College Text-Book of Geology*, rewritten and revised by R. T. Chamberlin and Paul McClintock (New York: H. Holt & Co., 1927), p. 304.

[17] T. C. Chamberlin and R. D. Salisbury, *A College Text-Book of Geology* (*ibid.*, 1909), p. 409.

[18] T. C. Chamberlin and R. D. Salisbury, *Geology*, Vol. I (New York: Holt & Co., 1904), p. 490.

[19] H. F. Cleland, *Geology, Physical and Historical* (New York, Cincinnati, etc.: Amer. Book Co., 1916), pp. 262–63.

[20] G. H. Cox, C. L. Dake, and G. A. Muilenburg, *Field Methods in Petroleum Geology* (New York: McGraw-Hill, 1921), pp. 221, 225.

[21] C. L. Dake and J. S. Brown, *Interpretation of Topographic and Geologic Maps* (New York: McGraw-Hill, 1925), p. 274. (*Throw* only considered.)

[22] G. L. Elles, *The Study of Geological Maps* (Cambridge: University Press, 1921), pp. 52, 60.

[23] W. H. Emmons, G. A. Thiel, C. R. Stauffer, and I. S. Allison, *Geology* (New York: McGraw-Hill, 1932), pp. 419, 421–22.

[24] A. W. Grabau, *A Comprehensive Geology*, Part I (Boston: Heath & Co., 1920), pp. 621–22.

[25] C. K. Leith, *Structural Geology* (Rev. ed.; New York: H. Holt & Co., 1923), p. 66.

[26] C. R. Longwell, *Outlines of Physical Geology* (New York: Wiley & Sons, 1930), pp. 281–82; C. R. Longwell, A. Knopf, and R. F. Flint, *A Textbook of Physical Geology* (*ibid.*, 1932), p. 315.

[27] W. J. Miller, *An Introduction to Geology* (New York: Van Nostrand & Co., 1928), p. 125.

Nevin,[28] Norton,[29] Pirsson and Schuchert,[30] Scott's 1932 revision,[31] and Quirke.[32]

This compilation shows that the definitions of *throw* and *heave* recommended by the committee as yet have not been generally accepted. That the committee did not meet the requirements of the textbook writers is apparent from the fact that these differences exist after 21 years. Either the definitions of the committee were open to technical objections or they were not clearly understood. At any rate, the fact remains that the terminology is still in need of standardization, and possibly simplification.

Many of the authors of elementary texts, in framing their definitions, evidently limit their consideration to cross sections for the sake of simplicity in presentation to students, and purposely omit the third dimension. Figure 2 shows the typical textbook illustration. In the same tenor the committee[33] suggested that classroom consideration be limited to *dip slip* faults "except with special students in geology or mining engineering." It may be that the authors who do use three-dimensional figures in their fault discussions are attempting to follow this recommendation. Texts dealing with *mining geology*, *structural geology*, or *field geology*, however, are necessarily intended for readers whose major interest is "geology or mining engineering," so that in these, at least, the effort to simplify cannot be the reason for not following the report of the committee.

Most of the textbooks consulted consider the components of fault movement of sufficient importance to deserve special names. The writer is thoroughly in accord with this view, but feels that the

[28] C. M. Nevin, *Principles of Structural Geology* (New York: Wiley & Sons, 1931), pp. 80–81.

[29] W. H. Norton, *The Elements of Geology* (Rev. ed.; Boston, etc.: Ginn & Co., 1921), p. 217.

[30] L. V. Pirsson and Charles Schuchert, *A Text-Book of Geology*, Part I (New York: Wiley & Sons, 1915), pp. 340–41; (2d rev. ed.; *ibid.*, 1920), pp. 362–63; (3d rev. ed.; *ibid.*, 1929), pp. 323–24; (*ibid.*, 1924), pp. 362–63.

[31] W. B. Scott, *An Introduction to Geology*, Vol. I (3d rev. ed.; New York: Macmillan & Co., 1932), pp. 434–35.

[32] T. T. Quirke, *Elements of Geology* (New York: H. Holt & Co., 1925), p. 252.

[33] H. F. Reid, *et al.*, "Report of the Committee on the Nomenclature of Faults," *op. cit.*, p. 185.

terms *throw* and *heave* have already been used in too many different senses[34] to render them desirable names for components of movement.

In the 1920 revision of their text, Pirsson and Schuchert[35] say,

> Thus there are three right angled axes . . . . [see Fig. 4 for a diagram of these] meeting in a common point . . . . and these may be termed the component axes of faulting. The directions and intercepts on these axes being known, the displacement can be calculated, and thus the problem of the fault solved. . . . .

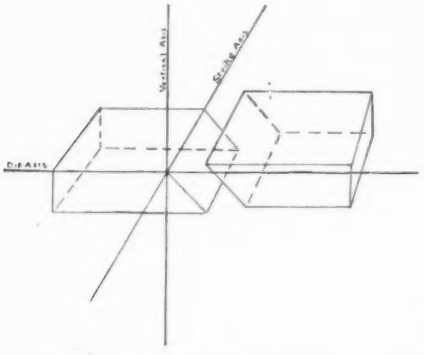

FIG. 4.—The axes suggested by Hubbert. If the strike axis be called the shove; the dip axis, the heave; and the vertical axis, the throw, the figure represents also the usage suggested by Pirsson & Schuchert. (Drafting by Louise Waldruff.)

They call these components *throw*, *heave*, and *shove*. The axes thus suggested would be a great improvement but for the fact that two of the old terms are retained with meanings which are not universally accepted.

A better suggestion was made by Hubbert,[36] who called attention to the fact that mathematicians and physicists use a system of rectangular co-ordinates in discussing three-dimensional data without apparent difficulty in nomenclature. According to this system the three axes are *strike direction*, *dip direction*, and *vertical*. Under such system a fault may be completely described by recording the components of movement in these three directions. Such a system would avoid confusion in terms. Hubbert's suggestion, however,

[34] John Challinor has recently pointed out the same variety of uses in "The Throw of a Fault," *Geol. Mag.*, Vol. LXX (1933), pp. 386–93, in which he discusses the geometric relations of the "throw" as well.

[35] *Op. cit.*, p. 324.

[36] M. K. Hubbert, "A Suggestion for the Simplification of Fault Descriptions," *Jour. Geol.*, Vol. XXXV (1927), pp. 264–69.

does not recommend itself to the average geologist because it is couched in unfamiliar mathematical language and symbols.

It seems likely that the usage of the majority of writers (*throw* and *heave* as components of fault movement) will finally be adopted, although the present confusion may continue to a greater or less degree into the next generation. To obviate this difficulty the writer proposes that descriptive language be substituted for the two terms in question. If faults are described by measuring the *vertical component* of the fault movement, the *horizontal component normal to the fault strike*, and the *horizontal component parallel to the fault strike*, there can be no misunderstanding of meaning. Greater clarity would justify the few additional words, and with these three measurements, together with the dip and the strike of a fault, it would be possible to picture all the fault relationships.

REVIEWS

The Deformation of the Earth's Crust. An inductive approach to the problems of diastrophism. By WALTER H. BUCHER. Princeton, N.J.: Princeton University Press, 1933. Pp. ix+518; figs. 100. $5.00.

If it is true that the field of structural geology is the common meeting-ground for all varieties of geologists—paleontologic, stratigraphic, petrographic, physiographic, geophysical, and economic—then a favorite subject for discussion and debate among all geologists for some time is sure to be this new book of Professor Bucher's. For here, written in vivid style and challenging manner, is a comprehensive effort to assemble all the broader facts of earth tectonics and to appraise conflicting theories of their interpretation. It is not a field manual of how to detect overturn or an exposition of the fundamental mechanics of rock failure. Instead, it is a critical analysis and synthesis, modeled somewhat after the manner of Suess' more encyclopedic *Das Antlitz der Erde*, of the broader problems with which structural geology is concerned. It thus supplements, rather than supplants, the standard textbooks of structural geology.

"Not until we have succeeded in the formulation of a body of specific laws, which are recognized as valid by all, can we expect to arrive at an intrinsically satisfactory solution of the problems of geotectonics" (p. vii). This important conclusion was reached years ago by Professor Bucher, who offered his first attempt at a formulation of such "laws" before a joint meeting of the Committee on Tectonics of the National Research Council and the Pick and Hammer Club of Washington in April, 1927. These "laws" were then amplified in a series of lectures presented at Princeton University in November, 1928, and the book is a further expansion of the material presented there.

Professor Bucher's original purpose seems to have been purely the compilation of a body of inductive generalizations which others might put together in whatever syntheses they chose. But with each new formulation has gone a partial revision of the earlier "laws" and the addition of new ones; and the author has apparently felt more and more the need to co-ordinate them and interpret their significance. In so doing, he has certainly made the generalizations more interesting and more stimulating reading, but he has also risked losing sight of the inductive approach which, after all, was to have been the unique contribution of the book.

Not that the reader ordinarily finds it difficult to distinguish facts from interpretations, for the author manifestly has striven to keep them sharply separate. But, once having chosen to discuss the significance of each generalization and to invest it "with all its possibilities" before proceeding to the next, the author then felt forced to interweave inferences and hypotheses in a way that certainly influenced the wording, if not the essential content, of the subsequent laws. As a result of this method of presentation, the main argument is so well knit and logical that any dubious conclusion reached early in the book plagues all the succeeding pages. The very fact that the author makes it easy for the reader to put his finger on the spot where he begins to disagree thus makes it somewhat difficult to view all the later "laws" objectively.

At the outset it is worth noting that the author expressly uses the word "law" in a much more inclusive sense than is customary, applying it not only to the relationships or time sequences between two or more variable phenomena ordinarily called natural laws, but also to simple definitions and classifications and to bare statements of geographic distribution. Interpreted thus, the number of possible "laws" is infinite. However, those chosen for formulation deal largely with the geographic pattern of past and present deformational features (such as mountainous "welts" and geosynclinal "furrows") and with generalizations about the depth to which deformation extended, the character of the rocks involved, and the time relationships and geologic history of the various structural features. The variety and scope of these "laws," as well as the general plan of the book, can perhaps best be indicated by a list of chapter headings:

Chapter	Title	Laws	Opinions
I.	The mobile belts	1–8	1–2
II.	Isostasy	9–12	3–8
III.	Continental margins and intracontinental mobile belts	13–15	9–10
IV.	The pattern of the mobile belts	16–19	11–14
V.	The diastrophic cycle	20–21	15–16
VI.	Marginal deformation	22	17
VII.	Deformation within the welts	23	18
VIII.	Special aspects of orogenic deformation	24–28	19–24
IX.	The intrusives	29–35	25–26
X.	Heterogeneous mobile belts and faulted belts of low mobility	36	27–28
XI.	Space relations of mobile belts	37–39	29–30
XII.	Time relations of mobile belts	40–43	31–35
XIII.	Epeirogenesis	44–46	36–39
XIV.	Summary and synthesis		

All the "laws," except two on the results of gravity measurements, deal with geology and physical geography, as ordinarily understood. Comparable generalizations of more purely geophysical data have not been included, although such matters as the physical properties of rocks, seismic evidence, thermal gradients, and the radioactivity of the earth's crust are mentioned briefly in the text. Most of the "laws" are illustrated by text and map with typical examples chosen from an enormous mass of literature covering all parts of the world, but particularly two areas with which the author is especially familiar, the central Rockies and western continental Europe. To this reviewer, the numerous maps, structure sections, and discussions of the western Alps, alone, are worth the price of the book.

From these "laws" and the derived opinions and sub-hypotheses, the author builds up, step by step, a comprehensive hypothesis, the essence of which is (*a*) that all crustal deformation is the product of alternate periods of world-wide tension and compression, the geosynclines (produced by tension) serving to localize the mountains (produced by later compression), and (*b*) that this alternating contraction and expansion of the globe is controlled in some way by fluctuations in the heat content of the subcrustal earth. In the development of this hypothesis, particular significance is attached to the fact that the earth's mountainous and geosynclinal "mobile belts" have a pattern strikingly similar to that of tension fractures on the surface of an expanded sphere.

The author is disarmingly impersonal about both his facts and his hypotheses. He warns that his theory depends entirely upon the validity of the "laws" and the correctness of his inferences from them. He urges the reader "first of all to test the soundness of the laws by his own field experience" and adds that "the writer expects his logic and his hypothetical ideas to be scrutinized as severely and, if found wanting, rejected as determinately as he has done with the ideas of others, [for] we can hope to make headway in our search for a road to understanding only by taking the task of critical reasoning as seriously as we take that of accurate observation" (p. viii).

The "laws," very properly, are considered "the main product of this investigation," but they "require further testing." It is certainly to be hoped that these generalizations will receive, in the geological literature of the next decade, the critical attention to which they are entitled. In the main they appear to be valid and carefully worded statements. Several would require minor qualifications to be completely acceptable to this reviewer, and a few seem more properly classed as opinions than "laws."

A number of the more closely related ones might profitably have been grouped together, and it appears that most of the definitions, classifications, and statements of geographic distribution might well have been omitted. On the other hand, it seems unfortunate that certain general statements made repeatedly in the text were not formulated among the "laws" in order to put them up for criticism and modification. For example, the statement, made in several places on pages 328–38, 482, and 483, that the highest elevations on an upfold or "welt" tend to lie opposite the lowest depressions in the adjacent trough or "furrow," might well have been made part of Law 7. Likewise, the generalization, which is made in various forms on pages 219, 403, 404, 443, 448, and 482, that the history of folded mountain systems leads from an early stage of relatively small uplift with much folding to a later stage of large uplift with little folding, might have been made part of Law 20, which states that "the typical orogenic cycle begins with geosynclinal depression and ends with a major uplift." With this same law it might also have been stated that normal faulting and acidic intrusions (Law 32) seem commonly to accompany the later stages of uplift.

Still these are minor criticisms, trivial beside the salient fact that here, with this body of "laws," we have a distinctive angle of attack and a nucleus of factual material around which to build. These are truly outstanding contributions that are certain to influence, and that may even entirely alter, the general method of approach to tectonic problems.

The theoretical portions of the book, on the other hand, are likely to arouse much criticism and debate. Not that the author allows himself to be carried away by his fine enthusiasm; most of the inferences are carefully drawn and the discussions of conflicting theories eminently fair. In fact, several of the discussions, such as the chapter entitled, "Deformation within the welts" (pointing out the importance of plastic deformation), and the sections on "The amount of crustal shortening" and "Zonal migration of furrowing and folding," seem models of excellence. And many will enjoy the neat handling of the Wegener hypothesis (though here the author accomplishes so thorough a job of deflation that one may feel tempted to remind him that none of his arguments applies with equal force against the possibility of some subordinate sliding). Still, several of the interpretations most vital to the author's principal conclusions are not convincing, and these seem certain to be challenged. This review is not the place to attempt complete analysis, but some principal lines of argument which the reviewer finds himself unable to follow may be indicated briefly.

Unfortunately, a doubtful interpretation enters early in the book. The author identifies the physical crust of the earth with the theoretical zone of compensation computed under the Hayford-Pratt concept of isostatic equilibrium (Opinions 5*a* and 5*b*). In so doing, he discards on grounds that seem inadequate the alternative Heiskanen-Airy concept of isostasy which many geologists, geophysicists, and geodesists prefer; and he apparently ignores the essential fact that gravity measurements give direct information not about the physical state of the earth's interior but about its density. To this reviewer, it appears that the earth's crust, defined solely by its physical property of considerable strength, is essentially independent of the zone of compensation; that is, the crust may be much thinner or even much thicker than the computed depth at which the weight of overlying rock columns becomes equal. Because of his Hayford-Pratt definition of the crust, the author meets several difficulties that seem needless; and, despite rather broad statements against the Airy hypothesis, he is forced to adopt its essential idea implicitly in Opinions 19, 20, 21, and 22. Had it not been for this early doubtful interpretation, the somewhat confusing discussion which follows Law 24 on pages 211–14, to explain the downward "expulsion" of matter from a thick crust, would not have been necessary.

Periods of world-wide tension are not yet popular among geologists. In his efforts to overcome prejudice and to prove the existence of such periods of tension, the author seems at times to go too far and to forget that *local* tension may be the perfectly normal accompaniment of a more *regional* compression. A thin block of modeling clay, covered with tinfoil and squeezed from its ends, yields first by close folding, then bulges outward, and finally tears along tensional fractures *while still subjected to compression;* a thick block of clay, similarly squeezed, bulges and tears immediately. Likewise, a series of tilted fault blocks does not necessarily prove *regional* tension. Neglecting strike-slip, the bounding normal faults record a certain amount of horizontal extension and the tilt of the blocks a certain amount of horizontal shortening. One cannot say that the *regional* stress was tensional, rather than compressional, until he has compared and found the extension to exceed the shortening. This seems not to have been done in the discussion of the Triassic basins of eastern United States, for example.

The fact that sinking geosynclines commonly (though perhaps not invariably) lay alongside rising land masses (Laws 5, 8*c*, 8*d*) seems at first thought to contradict the hypothesis that geosynclines are caused by world-wide tension. But under Bucher's general theory, the rising and

sinking were not truly contemporaneous. Instead, the land masses rose repeatedly during numerous brief epochs of world-wide compression, each but a few hundreds of thousands of years long; and the geosynclines sank recurrently during the intervening longer epochs of world-wide tension (Opinions 13, 15*b*, and 31). The brevity of the individual epochs and the repeated alternation of compression and tension are obviously essential to this explanation.

This brevity of the epochs of deformation is likewise vital to the author's hypothesis when he comes to consider the evidence for the world-wide synchroneity of crustal movements. If deformation were gradual instead of episodic, orogenic movements in different parts of the world might occur, quite accidentally, at the same time. Consequently, "it would not be revealing to find here and there definite evidence that in two or more regions orogenic deformation proceeded simultaneously," were it not for "the short, episodic duration of orogenic movements" (p. 411).

But this argument seems to defeat its own purpose. If the orogenic episodes are made brief enough to escape the suspicion of accidental coexistence, the difficulties of proving their world-wide synchronism become almost insuperable. The only valid evidence by which world-wide synchronism of crustal movements can be established is paleontologic. The number of world-wide crustal events demanded by Bucher's theory far exceeds the number of faunal or floral units that can be used for intercontinental correlations sufficiently precise to be accepted by most paleontologists. The briefer and more numerous the episodes, the more impossible it is to demonstrate strict contemporaneity. It almost seems necessary either to deny the brief episodic character of the movements, and with that the tensional origin of geosynclines, or else to admit that world-wide contemporaneity of crustal movements cannot be proved.

The author's theory of an accordion-like earth gets him into additional difficulties when he attempts to explain the repeated spread of seas across continental platforms at the very times when oceanic basins were supposed to be taking part in world-wide crustal expansions. To explain this anomaly, he offers a rather puzzling argument that the general heating thins the crust, brings about a less delicate isostatic balance (pp. 445–46) and causes the continents to sink toward the oceanic floors (pp. 447–48). The succeeding episode of world-wide cooling then raises the continents by isostatic adjustment until they again rise high above the oceanic floors. Unfortunately, however, this rather critical matter of the reversibility of the proposed mechanism is not adequately explained.

It may seem quibbling over minor matters; yet a protest is in order against the relevance of the question of formal logic with which the author frequently confronts an unacceptable theory: "Is it *necessary and sufficient* to explain the facts?" If this were a valid yardstick with which to measure theories, many of the author's could be discarded readily; but in a world of complex, many-factored phenomena, it is not. Alpine glaciers are neither necessary nor sufficient to level down great mountain masses; yet an important part of mountain erosion might well be glacial sculpture.

So it is with many of Bucher's theories. They may seem neither necessary nor sufficient to explain the present facts of crustal deformation; yet they may still represent important factors in a more comprehensive process. Whatever else may be said of them, they are the sort of theories that demand a re-examination of old data and old explanations and an active search for new facts. And that, in the last analysis, is the most that can be said for any theory. Taken as a whole, fact and theory together, the book is certainly a major contribution to structural geology.

The publishers are to be congratulated upon the volume. It is printed in fairly large, clear type on dull paper and strongly bound. Many of the line cuts, unfortunately, were reduced too much to be clearly legible, and several of the maps and sections carry no indication of their scale. Typographic errors are rare. Except for a discrepancy in numbering, apparently caused by the late insertion of Law 25 and Opinion 35 (a discrepancy that mars the otherwise excellent final chapter of "Summary and synthesis"), the numerous cross-references are accurate. The "laws" are brought together in a convenient appendix at the end of the volume; many readers will wish for a similar appendix of the opinions and a list of illustrations. The book appears to be well indexed under the three headings, "Terms and topics," "Geographic names," and "Authors."

WILLIAM W. RUBEY

A Manual of Foraminifera. By J. J. GALLOWAY. Bloomington, Ind.: Principia Press, 1933. Pp. 483; pls. 42. $6.50.

Some books almost write themselves. As you read one of this type, you are likely to become aware of the fact that the writer literally dashed it off—that he saw no urgent need for authenticating this measurement, these figures, or that statement. The other kind of book, and *A Manual of Foraminifera* is a good example of this latter sort, is one in which the reader sees long hours of research blended indelibly into every paragraph,

figure, and chart. As such, its title, *A Manual of Foraminifera*, is of course appropriate, but it is safe to predict that this important volume is destined to be still more aptly rechristened *Galloway's Manual*, for every page bristles with the author's vigorous statements and critical personality.

Recognizing D'Orbigny as the greatest student of the Foraminifera, and Brady as the "most brilliant" since D'Orbigny's time, Galloway finds little to commend his more than eight hundred other predecessors or contemporaries. But he nevertheless has waded through a large percentage of their more than four thousand papers, and has attempted to bring some order out of the chaos he found in them. As a consequence Galloway recognizes 542 valid genera, "more than twice as many as most workers." (Cushman in 1928 listed 413.) Sponsoring only a few new generic names, Galloway has rendered heroic service by placing in synonymy, or otherwise junking, 565 generic designations. By adhering to the Rules of Nomenclature much more closely than most of his co-workers, he has also been able to restore many an old family and generic name. Erecting two new families, the Chapmaniidae and the Cycloclypeidae, the author, nevertheless, reduces the number of families to 35, 10 less than the number appearing in Cushman's classification of 1928.

The first thirty-six pages of the book are given over to an all too brief discussion of the taxonomic position of Foraminifera, the philosophy of taxonomy, the history of foraminiferal classification, the morphology and reproduction of these Protozoa, and evolution and its corollaries in general.

The historical portion of this introduction is weak in that it omits mention of all work prior to 1826. There is thus no indication of the early labors of Beccarius, Plancus, Gualtieri, and Linnaeus, nor, for that matter, even of Lamarck himself. Furthermore, Dujardin's great discovery that the Foraminifera are Protozoa is only casually mentioned in connection with D'Orbigny's 1839 revision.

The principles of taxonomy and the corollaries of evolution are in general so well handled that most readers will certainly regret that the subjects did not receive still more extended treatment. In this section of the book, however, Galloway is so set on proving that the globular form is the ancestral type of foraminiferal test, and that arenaceous forms are not primitive, that he makes a number of statements which probably will stand a little re-wording. A brief examination of only one of these statements will bring out the point. Galloway says, "the arenaceous forms do not occur first in the geologic column; they appear in the Silurian and do

not become important until the Pennsylvanian, whereas the calcareous, non-arenaceous forms range from the pre-Cambrian, Cambrian and Ordovician onward." It must be stated that the author in general makes out a pretty good case for his primitive globular gelatinous Foraminifera, but such special pleadings as the foregoing quotation are liabilities rather than assets to his cause. There are authentic records of Ordovician arenaceous Foraminifera, and these forms are *abundant*, not rare, in Silurian rocks. These are *facts* well known to micropaleontologists. But even were there considerable doubt as to the validity of these statements, they would still rest on firmer foundations of *actual evidence* than the dictum that "calcareous, non-arenaceous forms range from the pre-Cambrian, Cambrian and Ordovician onward," however plausible this latter statement may be made to appear from philosophical reasoning.

But despite this and other non-objective treatments of controversial subjects, the book contains a wealth of valuable material not readily available elsewhere. The family trees are interesting and helpful, though they will not all be universally accepted. The keys for facilitating the allocation of specimens are well constructed, and the generic descriptions are excellent. Each genus, moreover, is illustrated by a figure of the genotype, and the law of priority has been rigidly applied in the determination of all valid names. Galloway is to be congratulated on writing a reference work which all active micropaleontologists will have to add to their libraries.

CAREY CRONEIS

Permo-carboniferous Fishes from East Greenland. By EIGIL NIELSEN. Copenhagen: C. A. Reitzels Forlag, Meddelelser om Grønland, Vol. LXXXVI, No. 3 (1932). Pp. 63; pls. 16. Kr. 4.00 unbound.

The members of Lauge Koch's Danish East Greenland expeditions of 1926–27 and 1929 collected numerous fish remains from marine Permo-Carboniferous rocks of Cape Stosch and to a lesser extent from other localities in East Greenland. The material is described by Nielsen, who distinguishes two new genera and four new species of fish. The interesting new genus *Fadenia*, named in honor of Dr. G. Seiden-Faden, is abundantly represented by teeth from all parts of the mouth and by specimens with teeth in association. *Fadenia* is an edestid similar to *Campodus* and *Helodus*, having a row of bilaterally symmetrical symphysial teeth and numerous transverse lateral rows of asymmetrical and variable teeth. Nielsen considers *Fadenia* the most primitive known edestid, as he does not believe that *Protodus* of the Lower Devonian is an edestid.

A second species represented by abundant remains is the new species *Agassizodus grønlandicus*. Nielsen removes *Agassizodus* from the synonymy of *Campodus* because the genotype, *C. agassizianus*, is known only from scattered lateral teeth and the general nature of the dentition is in doubt. He revises Eastman's restoration of the jaw of *Agassizodus* to bring the lateral series close together and in contact with the symphysial crowns in the anterior portion of the jaw, and suggests an arrangement similar to that of modern *Heterodontus*.

A new species of *Janassa*, *J. kochi*, is represented by a nearly complete specimen. The considerable amount of wear on the crown leads Nielsen to believe that this species fed on hard-shelled animals.

The new genus and species, *Arctacanthus uncinatus*, is a peculiar, high-crowned form with lateral barbs, and is probably conspecific with *Dolophonodus uncinatus* C. Branson from the Phosphoria of Wyoming. The correspondence of the specific names is accidental, and determination of priority in the generic name must depend upon actual publication dates of the two papers. Nielsen suggests that the form is the head spine of a chimaeroid; a conclusion which seems improbable. The affinities are rather with the rostral teeth of *Pristidae*.

Undeterminable species of *Cladodus*, *Copodus* (?), and *Acanthodes* or *Acanthodopsis*, and placoid scales of *Fadenia* and paleoniscids are figured. *Fadenia* is also represented by a crushed skull from which few features can be determined. Thin sections through the crowns of several species are excellently reproduced, and the plates in general are good. An extensive summary and discussion of the taxonomy and structure of the Bradyodonti is especially valuable.

C. C. BRANSON

The Geology of Texas. Vol. I, *Stratigraphy*. "The Pre-Paleozoic and Paleozoic Systems in Texas." By E. H. SELLARDS, pp. 15–231. "The Mesozoic Systems in Texas." By W. S. ADKINS, pp. 239–518. "Cenozoic Systems in Texas." By F. B. PLUMMER, pp. 519–818. "Bibliography and Subject Index of Texas Geology." By E. H. SELLARDS, pp. 819–996. Index to Vol. I, pp. 997–1007. Figs. 54; heliotype plates, 10; geologic map of Texas in colors. Bulletin of the University of Texas, No. 3232, July, 1933.

The area of Texas is 265,000 square miles, or more than one-twelfth that of the forty-eight states. Geologically, there are three different Texases: the pre-Cambrian, the Variscan, and the present day. The work

here reviewed mentions about 475 group, formation, and member names. A maximum total thickness of 60,000 feet of strata, exclusive of the pre-Cambrian, is now known in Texas. Of these, 28,725 feet, nearly half, are Paleozoic, comprising 3,000 feet of Cambrian and Ordovician, 1,000 feet of Silurian, 600 feet of Devonian, 750 feet of Mississippian, 11,900 feet of Pennsylvanian, and 11,575 feet of Permian. Mesozoic rocks have a total maximum thickness of 18,250 feet, with 1,500 feet of Triassic, about 750 feet of Jurassic, and 16,000 feet of Cretaceous. The Cenozoic maximum known thickness is 13,700 feet, of which 8,700 feet are Eocene. Cretaceous rocks are most important, covering the larger percentage of total area. In area of exposure the Eocene ranks next to the Cretaceous.

The Bibliography of Texas geology included in this work lists about 2,659 books and shorter papers. Some of the Cambrian, Lower Ordovician, Pennsylvanian, Permian, and Eocene fossils are illustrated in the plates. Notable text illustrations include system- and group-distribution and areal-formation maps, columnar, correlation, and cross sections, and diagrams of facies relationships and changes. The colored geologic map of the state portrays the considerable progress made since its predecessor was issued in 1916.

It is evident that the mere compilation and summarizing of the data on Texas stratigraphy is a task of great magnitude. The interpretation of the information and the generalizations and deductions included in this work have been made with excellent judgment. Much information is given on structure, physiography, and economic resources, although these subjects will be considered more fully in works now in the press or in preparation. Abundant subsurface data, from borings, are likewise included. Considering the magnitude of the work, errors—even typographical—are surprisingly few.

The statement made on page 125 that the great series of Pennsylvanian sediments of the Marathon basin was uninterrupted needs qualification, since there may prove to be two or three important breaks in the succession. It is stated on page 159 that the Castile gypsum has been proved to overlie the Capitan limestone, and the implication is that no part of the Castile can be the equivalent of the Capitan. This is perhaps not entirely acceptable, because on the flanks of the Guadalupe, Apache and Glass, mountains the Capitan, or its supposed equivalents, is known to interdigitate with the gypsum, and gypsum has been found in the Capitan limestone section in the Carlsbad Cavern. In the tables on pages 802 and 803, in the third column, some intrusive bodies other than dikes and sills should have been listed in the Chinati, Chisos, Chispa, Davis, Eagle,

Hueco, and Van Horn mountains. Dikes and sills in the Eagle Mountains are not listed.

It is perhaps invidious to commend any one section of this excellent work more than the others. It is desirable, however, to call to the attention of geologists the fact that nearly a third of this work, or 259 pages, is devoted to W. S. Adkins' account of the Cretaceous; that this is the first adequate discussion of the Cretaceous of the whole of Texas and is, moreover, one of the great contributions to the Western Hemisphere Cretaceous.

This work gives the reader an altogether satisfactory summary of what has become known of Texas stratigraphy as the result of 85 years of investigation. It also serves to indicate the major problems yet to be investigated and solved. Among these the following are noteworthy:

1. The stratigraphy and structure of the pre-Cambrian metamorphic rocks of the Llano and Van Horn uplifts.

2. The subdivision and fossil zonation of the Ellenburger Cambro-Ordovician group.

3. The problem of whether there was more than one diastrophic epoch in Pennsylvanian times in the Llano uplift. Further investigations are necessary in San Saba, McCulloch, Lampasas, and Burnet counties.

4. The petrography, petrology, time sequence, and ages of the igneous rocks of Trans-Pecos Texas.

5. The relationships between the Gulf Coastal Plain Cenozoic sedimentary and erosional history and those of the eastern Cordillera.

6. Age determinations, possible by the collection of vertebrate fossils, of the post-Eocene Coastal Plain sediments and of the intermontane deposits of the Rio Grande drainage basin in Trans-Pecos Texas.

CHARLES LAURENCE BAKER

The Marion Expedition to Davis Strait and Baffin Bay. Under the direction of the United States Coast Guard, 1928. Scientific Results, Part 3. *Arctic Ice, with Especial Reference to Its Distribution to the North Atlantic.* By EDWARD H. SMITH. Bull. 19, U.S. Treas. Dept. Coast Guard. Washington, 1931. Pp. 221; figs. 122.

As a result of the sinking of the Titanic in the spring of 1912, the International Ice Patrol was formed to study conditions of iceberg formation and drift, so that better means might be devised for combating this peril to international shipping. In 1928, the "Marion" of the U.S. Coast Guard was sent out to complete the work of this patrol. Three volumes have

been published, setting forth the results of this expedition; the present one, Part 3, gives the scientific results.

The author first presents a classification of ice and then discusses the extent of pack, land, and sea ice. Sea ice, though it forms over much larger areas than land ice, develops relatively few bergs, and these constitute no menace to shipping. The large icebergs come from glaciers; consequently their distribution and the method of iceberg formation from them (a process known as "calving") are subjects of detailed treatment.

The year-to-year variation in the number of bergs is attributed to diverse factors, such as winds, currents, pack ice, and winter temperatures. Of these, winds and currents are thought to be most important. Minor variations in the number of icebergs may be predicted from year to year, although an occasional season of exceptional ice (such as 1913) cannot always be foretold with certainty.

Mapping the most frequent paths is an important part of the work of the International Ice Patrol. It has been found that some of the bergs waste in shoal water south of Newfoundland; others go aground on the Grand Banks; but by far the largest number pass east of the Grand Banks southward into the shipping lanes. Within the last twenty years about twenty-four bergs have been reported as far south as latitude 40°.

The low temperatures of the polar currents are not due to the presence of large amounts of ice, or to the subtraction of heat in melting packs and bergs, but are now attributed to the small absorption of solar heat by the waters of the north polar regions.

The report makes available to glaciologists, oceanographers, and steamship companies a great deal of new information concerning ice conditions north of the Grand Banks.

H. W. STRALEY, III

Handbuch der vergleichenden Stratigraphie Deutschlands. Herausgegeben von der Preussischen Geologischen Landesanstalt (Prussian State Geological Survey). Vol. I, *Alluvium*. Editors: J. STOLLER, K. VON BÜLOW, and W. DIENEMANN. Berlin: Bornträger, 1931. Pp. xii + 424. Rm. 32.50.

It is planned that this large handbook of the stratigraphy of Germany is to consist of twelve volumes, each under a different editor with numerous collaborators. In the first volume the alluvium or post-Glacial epoch is considered, and the sedimentation, topographic changes, faunistic and floristic successions are described from the retreat of the Pleistocene ice

sheets to the beginning of what is called Present time, or about 1000 A.D. This study forms a link between geologic time and well-recorded human history.

The stages into which the post-Glacial epoch is divided are called in chronologic order: Subarctic, Transition, Pre-boreal, Atlantic, Subboreal, Subatlantic, and Present time.

A. C. NOÉ

Die geologische Erforschung Thüringens in älterer Zeit. By B. VON FREYBERG. Berlin: Bornträger, 1932. Pp. vi+160. Rm. 7.50.

The history of geologic exploration in Thuringia from its beginning in about 1700 to the appearance of H. Credner's *Survey of the Geology of Thuringia and the Harz Mountains* in 1843 is given in this book. With the publication of Credner's book the pioneer work was completed, and publications which have followed are special investigations and detailed maps.

A few classic regions have contributed particularly important chapters in the history of geology. One of them is Thuringia; others are, for instance, the Alps, the Swabian Jura, Westphalia, the Ural Mountains, some English counties, parts of the State of New York, Pennsylvania, the Lake Superior region, etc. What gave Thuringia its prominence was a wide range of geologic formations, wealth in fossils, and a variety of mining operations. The 143 years covered in the book, therefore, are about equally important for the history of stratigraphy, paleontology, tectonics, and economic geology.

Favorable for a study of the geology of Thuringia was its political organization. It consisted, until the German republic created a single state, Thüringen, of a number of small duchies, each of which had its museum, collections, and a bureau of mines. Together they supported the University of Jena, where mineralogy was always well represented. Even Goethe was interested in the geology of the little duchy of Weimar, where he was prime minister for a long time.

Thuringia has many and varied mineral resources, such as coal, lignite, peat, iron ore, manganese, gold, and copper. Most of these do not warrant exploitation in these times but were profitable in the eighteenth and early nineteenth centuries, when labor was very cheap and foreign competition unimportant.

One of the founders of stratigraphy was T. G. Lehmann, who in 1756 first classified the geologic formations as found in Thuringia; and much

of what he established has stood the test of time. E. F. von Schlotheim, who was prime minister of the duchy of Gotha, was a founder of modern paleontology in his *Beschreibungen merkwürdiger Kräuterabdrücke und Pflanzenversteinerungen*, 1804, and in his fundamental work *Petrefaktenkunde*, 1820.

It was in Thuringia that such familiar geologic terms as "Zechstein," "Rothliegendes," "Bunter Sandstein," "Muschelkalk," and "Keuper" originated.

A. C. Noé

Thin-Section Mineralogy. By Austin F. Rogers and Paul F. Kerr. New York: McGraw-Hill Book Co., 1933. Pp. 311; figs. 261. $3.00.

Part I (150 pages) by the junior author includes theory and technique, together with twelve determinative tables and a poorly-reproduced color chart. Part II by the senior author contains descriptions of the optical properties of 127 rock-forming minerals. Part I includes a discussion of the immersion method, together with index of refraction, birefringence, and axial angle tables which, in general, lack non-rock-forming minerals. A surprising amount of space is used in Part II to give values of indices of refraction to three decimal places; such figures are needed for immersion studies, but are rarely used in thin-section work; variations in composition-index diagrams are absent, but numerical limits are indicated.

The photographs and diagrams are excellent on the whole, though many of the latter which show optical properties of biaxial minerals seem to be at right angles to their normal positions. The researches of X-ray students as regards silicate formulas seem to have been neglected in the main; this is particularly unfortunate as applied to the amphiboles. Periclase, mullite, and even lechatelierite are described, though rhodonite, for example, is not. The use of *polarizing* rather than *petrographic* or *mineralogic* microscope is to be commended. The publication of such a well-illustrated book at so reasonable a price will be a boon to teachers of, and students in, short courses in thin-section work; for concise, clear, and well-balanced coverage of so much ground it has no rival.

D. J. Fisher

The Oil and Gas Resources of New Mexico. By Dean E. Winchester. New Mexico School of Mines, State Bureau of Mines and Mineral Resources, Socorro. Bulletin 9. 1933. Pp. 223; figs. 11; pls. 33. $1.50.

This valuable work, of necessity compilation in the main, contains brief descriptions of the rocks of the state (38 pages), followed by sum-

mary descriptions of the various pools and potentially favorable structures, grouped according to five areas. State geologic and oil and gas maps, as well as structural maps of many limited areas, add greatly to the utility of the bulletin. The last ten pages preceding the Bibliography are devoted to refining, transportation, bituminous sandstone, and geophysics.

Permeability variations, rather than structural irregularities, are regarded as responsible for accumulations at Artesia, Cooper, Jal, and Maljamar. Deeper drilling in the northeast area and further exploration in the southeast are regarded as having promising possibilities.

D. J. F.

Physics of the Earth: Part IV, *The Age of the Earth.* National Research Council, Bull. 80. Washington: National Academy of Sciences, 1931. Pp. v+487. $5.00.

The fourth volume of the series treats in detail the four principal methods of estimating the age of the earth. These are based on (1) the sedimentary record and evolutionary processes (by Charles Schuchert); (2) the salt content of the oceans (by Adolph Knopf); (3) age determinations of radioactive minerals in rocks (by A. F. Kovarik and Arthur Holmes); and (4) astronomical observations. The most exhaustive treatment is that of radioactivity, which is a fairly complete discussion of the principles and methods underlying the determination of the age of minerals from their radioactive content.

In the section dealing with the accumulation of sediments Schuchert works backward from the age derived by radioactive methods to determine the rate of accumulation of limestone, sandstone, and shale. The result seems to him to be of the correct order of magnitude. It is pointed out, however, that the recent work of Bradley, Marr, and others, on varved deposits is likely to point the way to reliable estimates from the sedimentary record itself. No method exists for determining the age of the earth from the evolutionary processes, because the rate is unknown.

The "age of the ocean," estimated by the sodium method, is of the order of magnitude of 100 million years. Both assumptions upon which the method is predicated, however, are fallacious; namely, that the rate of accumulation of salt has been constant, and that there has been no subtraction of salt from the oceans.

The radioactive method involves the fewest assumptions, but fewer acceptable determinations have been made. The oldest known mineral is a uraninite from Sinyaya Pala, Carelia, Russia, which gives 1,800 million

years as the age of this part of the pre-Cambrian. One can, therefore, rest assured that the planet is more than 2,000 million years old, and probably much older. It is brought out that estimates based on pleochroic halos cannot be relied upon.

Astronomic data give an age for the planetary system of the order of magnitude of 10 billion to a trillion years. These estimates are lacking in definiteness and may be used only as a check on the other methods.

H. W. STRALEY, III

The Geology and Paleontology of British Somaliland. Part I, *The Geology of British Somaliland.* By W. A. MACFADYEN, with an Appendix by A. HARKER. Government of the Somaliland Protectorate, 1933. Pp. 87; pls. 4.

An excellent stratigraphic summary of British Somaliland is given in this volume, although it is unfortunate that the exigencies of publication necessitated appearance before the paleontological work upon the fossil collections of the Anglo-Persian Oil Company (1925) and the Somaliland Petroleum Company (1928–30) had been completed.

The older rocks, both igneous and metamorphic, are lumped together as Archean, although no evidence is cited to show that the whole of the Proterozoic and Paleozoic is unrepresented. But from the Triassic to the Holocene the stratigraphy is treated in detail.

The structure is dominated by normal faulting. Though some minor folds occur, no folded mountain ranges were discovered. There are roughly three systems of faults: that of the Gulf of Aden, trending east-northeast; the Red Sea system, trending northwest; and the East African, trending north. Two episodes of faulting were recognized: late Eocene or early Oligocene, and late Pliocene. The dip of the faults is not high for normal faults (38° to 70°), but the "throw" is large, measuring from 310 meters to 6 kilometers.

The Bibliography supplements those of Gregory and Krenkle. In Appendix I, Harker gives a short description of the igneous and metamorphic rock collections of the Somaliland Petroleum Company. The rainfall, drainage, and water resources are discussed in Appendix II. A complete list of all known fossil collecting grounds in the protectorate is found in Appendix III, together with a number of geologic columns.

H. W. STRALEY, III

The Syntaxis of the North-West Himalaya; Its Rocks, Tectonics, and Orogeny. By D. N. WADIA. Records of the Geological Survey of India, Vol. LXV, Part 2 (September, 1931). Pp. 190–220; Pls. 3–8.

After following a northwesterly trend for 1,200 miles, the Himalaya system, within a few tens of miles, makes a right angle turn to the southwest, forming a re-entrant about an arm that projects northward from Gondwana foreland. Both the stratigraphy and structure of the formations exposed in this inflexion are discussed in the report, but the structural studies are of more general interest.

On the projecting arm of the foreland are exposed superficially folded Tertiary sediments. Immediately to the east, north, and west lies the arc of the autochthonous folded belt of sediments and volcanics ranging in age from Eocene to Carboniferous. This belt is bounded on the concave side by a reverse fault and on the convex side by an overthrust along which the pre-Cambrian metamorphics of the nappe zone of the inner Himalaya have moved toward the center of the arc. The geologic strike of the formations in both the folded belt and the nappe zone curve about the re-entrant. This inflexion is preserved as far north as the foot of the Pamirs, beyond the axis of the Himalaya Range.

The explanation of the formation of the syntaxis favored by the author is that the original pressure acted directly from the north, but that when the rising folds were pushed against the northern promontory of Gondwana foreland they were molded about it by the pressure which was now resolved into two components from the northeast and northwest. It is suggested that this promontory, buried under Tertiary sediments, may be an ancient folded mountain chain or a projecting tongue, perhaps a horst, of the Archean shield.

A geologic map of the syntaxis to the scale of 16 miles to 1 inch accompanies the paper.

A point of interest is the observation at one place of an apparently conformable passage of the pre-Cambrian series into supposed Cambrian strata.

EDWARD L. TULLIS

Elementary Exercises in Topographic and Structural Geology. By A. K. LOBECK. New York: Geographical Press, Columbia University, 1934. Pp. 8; figs. 31. $0.35; 10 or more, $0.25.

This series of thirty-one exercises is published on two sheets of the same size as the *Lobeck Physiographic Diagram* and forms the latest of the Lo-

beck series on *General Physiography, Geography,* and *Geology.* Each exercise consists of a partially completed diagram approximately 7 in. × $4\frac{1}{4}$ in. in size with an accompanying text of explanations, instructions, and questions. The diagrams, although in some cases somewhat artificial or unnatural, are well executed; and the text is simple and clear. The first fifteen exercises illustrate two- and three-dimensional methods of depicting various types of topographic forms; Exercises 16–19 show the method of plotting outcrops on contour maps; Exercises 20–23 show graphic methods of solution of dip and strike problems; and Exercises 24–31, with the accompanying diagrams cleverly designed so that they may be folded to make three-dimensional figures, are problems dealing with flat-lying, folded, and faulted beds.

The following criticisms may be made: (1) too much "busy-work" is required, especially in the first few exercises; (2) the series as a whole lacks unity; (3) the exercises seem to emphasize mechanics of construction rather than physiographic and geologic interpretation; and (4) there are no exercises on unconformities and igneous rock relationships. Teachers will, however, find the exercises valuable as introductory material for the study of topographic and geologic maps.

GORDON RITTENHOUSE

Oberrheinischer Fossilkatalog. Edited by W. SALOMON-CALVI. Lieferungen 1 and 2. Berlin: Bornträger, 1931 and 1932. Rm. 26 and 18.

In this catalogue it is endeavored to give a list, first, of all animal and plant fossils which have been described from the region of the Upper Rhine, and, second, of such fossils as had been originally described from other regions but the descriptions of which were augmented and improved by the discovery of the same species in the Upper Rhine Valley. The literature has been critically examined, and the localities are given with accurate geological horizons.

The catalogue is to appear in three booklets (*Lieferungen*) containing:

1. "Paleozoic Invertebrates and Vertebrates." By M. Pfannenstiel.
2. "Triassic Invertebrates." By W. Scheffen.
3. "Jurassic Invertebrates." By W. Deecke.
4. "Triassic and Jurassic Vertebrates." By M. Pfannenstiel.
5. "Paleozoic and Mesozoic Plants." By K. Frentzen.
6. "Tertiary Foraminifera." By H. Jüngst.
7. "Neozoic Invertebrates, Part I." By W. Wenz.

8. "Neozoic Fishes." By W. Weiler.
9. "Neozoic Invertebrates, Part II." By O. Schmidtgen.
10. "Neozoic Plants." By R. Kränzel.

Lieferungen 1 and 2 contain Nos. 1–8.

A. C. Noé

Geologie der Erde. Part I, Geologie Südamerikas. By H. Gerth. Berlin: Gebrüder Bornträger, 1932. Pp. vi+199; illust., pls. 22 Rm.

In the series "Geologie der Erde" has been published a volume dealing with the geology of South America from the earliest times to the end of the Paleozoic age. It is to be hoped that the geologic history of post-Paleozoic South America will soon follow.

The author discusses first the geologic structure of the South American continent and later takes up the Paleozoic stratigraphy. He pays a great deal of attention to the orogenetic processes and to paleontological evidence. The latter is much used in connection with the Permian *Glossopteris* floras in order to make possible various correlations between the geologic subdivisions of South America as well as with other continents of the Southern Hemisphere and with India.

A. C. Noé

Report on Aërial Survey Operations in Australia during 1932. By W. G. Woolnough. Canberra: Government Printer, 1933. Pp. 83.

This report gives the results of an aërial photographic survey undertaken to try out this method of general reconnaissance work in various parts of Australia. The selected route extended completely around the continent and thus tested the value of such a survey for the full range of conditions occurring in Australia. It was possible to detect from the air, both visually and photographically, many continuities of geologic structure which are entirely lost on the ground. Much useful information was obtained, particularly on potential oil fields.

R. T. C.

Geology and Mineral Deposits of Southern Yuma County, Arizona. By Eldred D. Wilson. Arizona Bureau of Mines, Geol. Ser., No. 7, Bull. 134. 1933. Pp. 236.

This volume is a prospector's guide, rather than a detailed geological report. Twenty-six mountain ranges come under consideration, of which

the most important are the Trigo, Castle Dome, Kofa, Little Horn, and Gila ranges.

The metamorphic rocks of the area, which the author believes to be younger than the pre-Cambrian, consist mainly of sedimentary schists, although gneiss and schist of igneous origin are present. The igneous rocks, which cover fully two-thirds of the area, are largely Mesozoic granites, intruded and covered by Cenozoic dikes and flows. The sedimentary rocks are somewhat doubtfully placed in the Cretaceous, Miocene, Pliocene, and Pleistocene.

Mineralization has occurred along the faults which border the mountain ranges, as well as along other fractures. The principal mineral product is gold, although copper, lead, and silver are found in commercial quantities. Both mesothermal and epithermal veins are known to be present, as well as rich gold placers.

H. W. STRALEY, III

Applied Geophysics in the Search for Minerals. By A. S. EVE and D. A. KEYS. Cambridge: University Press; New York: Macmillan Co. (2d ed.), 1933. Pp. 296; figs. 112. $4.25.

The changes in the second edition of this well-known book, aside from some minor revisions in the interest of accuracy of statement, are the addition of 40 pages and 20 figures to the text and Appendix, and of 1 page to the Bibliography. It is to be regretted that, at a time when rapid changes are occurring in the field of applied geophysics, this previously excellent book (M. K. Hubbert, "Review of Applied Geophysics in the Search for Minerals," *Jour. Geol.*, Vol. XXXVIII [1930], p. 191) was not revised to include those advances which were made up to the time of its publication. The chapter on seismic methods is in the greatest need of revision. For example, the brief statements concerning the reflection method are identical with those of the now antiquated treatment of that subject in the first edition. The authors state that the magnetometer is of value in surveying salt domes, but the reviewer could find no mention of the use of that instrument in outlining buried granite ridges. Among the electrical methods the important potential-drop-ratio methods are given only an inadequate 18 lines. In general the book is written largely from the point of view of the physicist.

EDWARD L. TULLIS